Economic and Social Commission for Asia and the Pacific

Water Resources Journal

E/ESCAP/SER.C/131

December 1981

Mar del Plata Action Plan

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United Nations

ESCAP and natural resources

The natural resources programme of ESCAP assists Asian and Pacific countries in strengthening their capability to meet their national objectives in three key resource areas: water, minerals and energy.

The ESCAP Natural Resources Division provides, on request, expert assistance in planning and implementing acitivities concerning assessment, development and efficient use and management of ESCAP member countries' natural resources.

The Water Resources Section of the Division promotes a comprehensive approach to development and management of national water resources, keyed to the global recommendations of the United Nations Water Conference at Mar del Plata in 1977. The Section's programme concentrates on improvement of water resources data systems, water policy and legislation, technical advisory services, efficiency in water use and dissemination of technical information through its publications. Joint activities with other organizations concern the Typhoon Operational Experiment (TOPEX) and mitigation of damage from cyclones, floods and droughts.

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ESCAP Natural Resources Division

DESIGN OF LOW-HEAD HYDRAULIC STRUCTURES
Water Resources Series No. 45, United Nations publication, Sales No.E.74.II.F.12. Price $US 11.00.

PROCEEDINGS OF THE FIRST SESSION OF THE COMMITTEE ON NATURAL RESOURCES
Water Resources Series No.46, United Nations publication, Sales No.E.76.II.F.2. Price $US 9.00.

PROCEEDINGS OF THE SYMPOSIUM ON SOCIAL AND NON-ECONOMIC FACTORS IN WATER RESOURCES DEVELOPMENT
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PROCEEDINGS OF THE REGIONAL SEMINAR ON COMMUNITY PREPAREDNESS AND DISASTER PREVENTION
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Water Resources Series No.51, United Nations publication, Sales No.E.79.II.F.16. Price $US 9.00.

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Water Resources Series No.52, United Nations publication, Sales No.E.80.II.F.17. Price $US 21.00.

PROCEEDINGS OF THE EXPERT WORKING GROUP MEETINGS ON WATER RESOURCES DATA SYSTEMS AND WATER-USE DATA
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Water Resources Series No.55, United Nations publication, Sales No.E.81.II.F.11. $US 8.00

ESCAP water resources journal

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The Economic and Social Commission for Asia and the Pacific is the regional arm of the United Nations, with headquarters in Thailand. It is administratively responsible to the Secretary-General of the United Nations. At the same time it is responsible to the member countries of the ESCAP region and is subject to their parliamentary control and guidance in policy matters, under the over-all control of the Economic and Social Council.

Water Resources Journal is a quarterly periodical of the Natural Resources Division of ESCAP. Published continuously since September 1949, the *Journal* aims to provide useful technical information on water resources for national agencies and development programmes in Asian and Pacific countries.

The contents of *Water Resources Journal* include reports on water resources programmes relevant to the ESCAP region, news of current developments and other information of regional interest, accounts of national experience applicable to other Asian and Pacific countries, and technical articles reprinted from various sources around the world. The focus is on ideas and techniques which can be applied in the context of national programmes in the region.

Water Resources Journal is distributed in Asian and Pacific countries to national agencies and programme offices concerned with water resources development, and to readers elsewhere on a selective basis. Requests and other inquiries should be addressed to:

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MAR DEL PLATA ACTION PLAN

HOW MUCH PROGRESS HAVE WE MADE?

As a first step to reviewing progress made in implementing the 1977 Mar del Plata Action Plan, the Secretary-General of the United Nations circulated a questionnaire among Governments in 1980. A total of 60 developing countries and 15 industrialized countries had replied to the questionnaire by January 1981, and their answers have been analysed in a report presented to the Committee on Natural Resources in May 1981 (E/C.7/117). Information from that report is summarized here in an attempt to give readers of Water Resources Journal *a snapshot image of the status of development in this field at the outset of the Water Decade, 1981-1990.*

Assessment of water resources

Two types of data are collected by government agencies for use in assessing available water resources in most countries. Time-series data, such as meteorological, surface-water and ground-water measurements, are gathered over a period of time and in different locations in order to analyse variability. Other basic data, independent of time, consist of physiographical, geological and hydrogeological measurements.

A number of agencies usually require these data in each country, in managing particular aspects of water use under their responsibility: for example, agencies concerned with industrial and municipal water supply, irrigation and drainage, hydroelectric power production, navigation, recreation, watershed management, reduction in flood and drought damage, wildlife and environmental protection, among other concerns. Each agency is usually responsible for collecting its own data, and does so without co-ordinating with other agencies which are using similar data. The result is that data collection activity in most countries is duplicative, and produces similar information in non-standardized formats which limits its usefulness to all but a few specific concerns.

The survey questionnaire sought information from Governments on action taken or planned since the Mar del Plata Action Plan was formulated in 1977, in the areas of data collection, processing, storage and dissemination, as well as areal coverage, under the following headings.

In most cases, however, it was not possible to determine from the responses the extent, adequacy or quality of any improvements made.

(a) *Observation networks.* The density of networks for collecting time-series as well as time-independent data has grown in most developing and industrialized countries. Additional networks for meteorological, surface-water and ground-water data have been set up or planned in about 60 per cent of the 60 developing countries which responded and in about 45 per cent of the 15 industrialized countries which responded. Networks for physiographical, geological and hydrogeological data parameters have also increased, in about 40 to 50 per cent of the responding developing countries and in 30 to 60 per cent of the developed countries.

(b) *Data processing, storage, retrieval and dissemination.* Since 1977, Governments of 42 per cent of the developing countries in the sample have expanded their facilities (including computers) for processing and storage of hydrological and related water-resources data, and 47 per cent indicated that means of information dissemination have been improved. Developed countries reported a relatively higher percentage of achievement in installation of data processing and storage facilities, and in dissemination of data to users.

(c) *Areal assessment.* About 53 per cent of the sample of developing countries reported that they have expanded their area of data collecting activities, while 77 per cent of them plan to expand areal coverage. Industrialized countries reported actual and planned expansion in 67 per cent and 60 per cent, respectively, of the cases.

(d) *Remote sensing and isotope techniques.* Application of remote sensing and isotope techniques in hydrological surveys was reported in 48 per cent and 28 per cent, respectively, of the responding developing countries. Conversely, in 45 per cent and 60 per cent, respectively, of those countries there is no official intention at present of applying these techniques. Among the industrialized countries, remote sensing techniques have been applied in 53 per cent of the sample, while isotope techniques are practised in 73 per cent of them.

(c) *New national agencies or mechanisms.* Of the 60 responding developing countries, 13 countries have already set up a new national institution or special mechanism to prepare water resources assessment, and another 20 have plans to create new national bodies in the near future.

Water for agriculture

The United Nations Water Conference in 1977, which produced the Mar del Plata Action Plan, also adopted the Action Programme on Water for Agriculture for increasing food and agricultural production and productivity. The Programme aims to bring new land under irrigation, to improve the efficiency of existing schemes, and to expand rain-fed agriculture, among other goals. The survey netted information from Governments relating to water resources development and use in agriculture under the following four headings. Responses from developing countries are summarized below.

(a) *National programmes.* Most (65 per cent) of the developing countries replied that they have taken action to assess, formulate and/or update national programmes for development of agricultural water supplies since the Water Conference. Plans have been made for action in 57 per cent of the response sample. The general programme areas include irrigation, drainage and reclamation, flood protection, water supply for livestock, and aquaculture in rural areas. Regarding extent and cost of agricultural water development, estimates are available in 35 per cent of the developing countries and are being prepared in 58 per cent of them, within national plan periods in the time frame of 1976-1990.

(b) *Trained manpower needs.* A total of 31 of the responding developing countries (or 53 per cent) reported that they have already taken action to assess needs for trained manpower needed in implementing programmes for agricultural water development. An equal percentage also indicated that they have plans to assess these needs. The needs cover professional and technical training, research staff, extension staff and basic education staff. A total of 42 Governments reported having taken measures or are planning to do so; almost all of them mentioned the first category, professional and technical training, while about two thirds mentioned the other categories as well.

(c) *National advisory services.* About half of the developing countries in the sample have already begun to promote national advisory services in support of agricultural water development, and about the same percentage have plans to do so. These services cover such activities as planning, design, construction, operation and maintenance, and equipment supply.

(d) *Constraints, and means of overcoming them.* Shortages of qualified manpower and of financial resources, lack of equipment, and inadequate institutions were widely viewed by developing countries as impediments to their efforts to develop and manage agricultural water resources. In order to overcome these programme constraints, the countries affirmed in their survey responses that international co-operation could play an important role, mostly by providing training for national personnel (in 80 per cent of the responses), equipment (in 65 per cent of responses) and technical advice (in 63 per cent of responses).

Information on water

The information aspects of water resource development include publicity, education, training, research and development activities.

(a) *Education, training.* Manpower needs, and working and living conditions among water resources manpower were the focus in this category. Surveys to assess manpower needs have been carried out since 1977 or planned in 80 per cent of the responding developing countries. While 23 of the 61 respondents in this category indicated no plans to conduct a comprehensive manpower survey, it is assumed that some of these countries may already have acquired adequate knowledge of their needs through earlier surveys. The manpower situation in many developing countries, in terms of skilled researchers, administrators, planners, policy-makers and lawyers, has remained virtually the same as it was in 1977. Some countries have increased their numbers of university-trained engineers and other professionals.

Fifty countries reported having taken measures to expand educational institutions, aimed at alleviating shortages of: (i) lower-level technicians (42 countries); (ii) higher-level technicians, mid-level engineers and managers (40 countries); and (iii) university-trained engineers and other specialists (30 countries). Fewer countries indicated that they are trying to reduce the shortages of research scientists, administrators, policy-makers, planners and lawyers.

(b) *Research, development.* Steps to establish or strengthen research institutes and laboratories in water have been taken or planned by 45 of the 60 developing countries responding in this category. Twenty-four countries have already taken action; 34 countries have made plans to initiate or continue taking action.

(c) *Public information.* A total of 50 Governments (about 83 per cent of the response sample) have taken concrete measures, and/or have plans to do so, for promoting public understanding of water use and management. Public information activities appear

to be more intense in regions of the world where water development is relatively more advanced (i.e. in Asia and the Pacific, *vis-à-vis* Africa and Latin America).

(d) *Constraints, and means to overcome them.* The constraints to advances in education and research programme development have been listed by the developing-country Governments as: (i) shortage of qualified teaching staff; (ii) lack of equipment and teaching aids; (iii) funding limitations; (iv) lack of properly designed curricula; (v) lack of students suitably prepared; (vi) institutional problems. Staff and funding constraints loom largest (in 73 and 78 per cent, respectively, of the responses) with regard to research institutes. For training of technicians, the greatest constraints lie in equipment/teaching aids and funding (in 72 and 73 per cent, respectively, of the responses).

A large majority of the respondents felt that international support would be helpful in overcoming these constraints in education and research programmes. From 80 to 90 per cent of them listed the following types of assistance needed: equipment, fellowships/training, funds and expertise. Technical advice and consultants are felt to be needed to a lesser extent.

Co-operation with other developing countries

The Mar del Plata Action Plan calls for strengthening technical co-operation among developing countries (TCDC) in order to meet water development objectives. As indicated in the survey responses, the two types of TCDC activity in which the sample of 60 developing countries has achieved the most significant progress since 1977 are information exchange (67 per cent of respondents) and technical/economic co-operation (58 per cent of respondents). Lesser progress in co-operative activity was achieved in joint ventures (40 per cent), institution building (35 per cent), and expertise/consultancy exchange (33 per cent). For the future, however, the responding countries registered much higher levels (65 to 92 per cent) of interest in co-operative activity in the areas listed above, and in the standardization of engineering services as well.

UNDP information role

Mailing list expansion. Target individuals and institutions are expected to reach a total of 15,000 to 16,000 on the mailing list for information materials on the International Drinking Water Supply and Sanitation Decade (1981-1990). Building on a core of 5,000 selected names at the beginning of the Water Decade, UNDP information staff have already systematically expanded the total to 11,000 names of institutions or people working in fields relevant to the activities and goals of the Water Decade. Eventually another 4,000 to 5,000 names may be added, as national programmes and international agencies develop their own programmes in pursuit of the Decade goals. Audience categories include communications media, intergovernmental organizations, governmental agencies, financial or business institutions, research and educational institutions, health and medical service agencies, non-governmental organizations (NGOs), and unaffiliated individuals.

Bibliography. Research activities in preparation of information material on the Water Decade turned up well over 300 books and other publications, which have been listed in a bibliography published by the UNDP Division of Information. The list, in English, has been reproduced in limited numbers for use by others engaged in research on Decade-related subjects. Copies of the bibliography may be requested from:

UNDP, Division of Information
Room DC-1900 (Mr. W. Hailemelekot)
1 United Nations Plaza
First Avenue
New York, NY 10017, USA

Theme film: "Journey for Survival". A film on the theme of the Water Decade entitled "Journey for Survival" has been produced by UNDP, UNICEF and WHO, and was released in June 1981. The 16 mm colour film runs for 15 minutes with alternative sound tracks in English, French, Spanish and Arabic.

"Journey for Survival" depicts the severe social and economic problems that lack of access to water supply and sanitation facilities impose on more than half the world's population. Daily treks must be undertaken, mostly by women and children, in search of water for survival, a search made even more difficult because the distant water supplies so desperately sought are often inadequate and contaminated.

The film "travels" from the parched deserts of Bangladesh, through Sudan's sandy plains to the towering Yemeni heights and the rugged trails of Peru's Altiplato.

The Decade, an international effort based on national commitments, aims at providing clean water and adequate sanitation for all by the year 1990. A Ghanaian environmentalist and a Napalese stateman explain key elements of the Decade's strategy: national commitment, community participation and the right choice of technology. The film ends on a hopeful note: "Technologies are simple. Resources are available. All that is required is commitment".

For information on obtaining the film please contact UNDP, Division of Information.

WATER RESOURCES AMONG THE LEAST-DEVELOPED: A 1981 BRIEF ON NEEDS AND ACTION PLANS

Water resources rank among the basic areas for priority in development among the world's least-developed countries, as testified at the recent United Nations Conference on the Least-Developed Countries. Held at Paris from 1 to 14 September 1981, the Conference provided a forum at which to air the needs and decide on means for tackling problems of development in these countries with the greatest needs.

Seven Asian and Pacific countries in this category submitted papers on their sectoral needs and plans for meeting them: Afghanistan, Bangladesh, Bhutan, Lao People's Democratic Republic, Maldives, Nepal and Samoa. Excerpts from the texts of their papers, as prepared by the Conference secretariat, are presented in the following paragraphs to illustrate some of the major water-related development issues in the least-developed Asian and Pacific countries.

AFGHANISTAN

Irrigation and other hydraulic projects. A number of projects are in various stages of execution or planning for the purpose of harnessing water resources for the irrigation of agricultural land and/or the generation of electricity. Surveys are also being carried out or envisaged to determine the potential water resources that could be tapped. In addition, attention is being given to drainage, flood control, the prevention of water wastage, the repair and maintenance of old irrigation channels. It is estimated that the aggregate cost of the projects in question will amount to about 4 billion Afghanis. Some of the projects were to have been supported by certain international financial institutions whose aid is suspended.

Energy. It is proposed to construct a number of hydroelectric power stations, to expand or improve some existing ones and to build electricity transmission lines, for the purpose of supplying certain urban and industrial centres with electricity or increasing the supply of these centres. These schemes will call for investments totalling about 12 billion Afghanis.

Social sector. Aware of the serious deficiencies in this sector, the Government proposes various schemes for improving health, education, literacy, sanitation, the water supply and, in general, the conditions of life of the population. As evidence of its concern, the Government states that almost 15 per cent of the 1980/81 budget has been earmarked for this sector. In addition to those relating to education and health, a number of activities are to be undertaken: (i) To meet basic needs (food, clothing, housing, supply of drinking water); (ii) To augment employment opportunities; (iii) To eradicate illiteracy; (iv) To provide maternal and child care.

Water supply and sanitation. A number of projects are in the process of execution or planning for the purpose of providing Kabul, certain provincial centres and some rural areas with supplies of safe drinking water and with improved sewerage systems. Some of these projects are supported by UNICEF and/or WHO, others receive bilateral assistance. The total cost of these projects is estimated at about 6 billion Afghanis.

BANGLADESH

Housing, sanitation, drinking water supply. At the moment adequate shelter, piped water, sanitation and other community facilities are available only in about 100 urban and semi-urban locations in the country, serving about 10 per cent of the total population; the remainder of the population lacks these services, and in rural areas the water supply is often insanitary. Even in urban areas, only about 35 per cent of the inhabitants have access to piped water, and modern sewerage exists only in Dacca and Chittagong (and even there only partially). There is little town planning or land use planning, and where such plans exist they are poorly enforced. To remedy this state of affairs, at least to some extent, it is proposed during the first half of the 1980s to extend the public sector infrastructure, services and facilities to about 1,200 growth centres, to make safe drinking water available to more people (one tubewell for every 75 persons) in the rural areas, to modernize the water supply and sewage disposal systems in Dacca and Chittagong, to provide sanitation units for every village, to construct 40,000 housing units (mostly in the private sector) and to undertake other projects providing basic facilities to the population. For this purpose the current Plan envisages an investment programme of about Tk22 billion, of which Tk12 billion will be by the public sector and Tk10 billion by the private sector.

Agriculture

Although Bangladesh possesses fertile land and abundant surface and subsoil water, the productivity of the agriculture sector is still low for a number of reasons. These include the fragmentation of land

Document numbers for the country reports or summaries cited in these pages are as follows.

Afghanistan	A/CONF.104/SP/3
Bangladesh	A/CONF.104/SP/7
Bhutan	A/CONF.104/SP/1
Lao People's Democratic Republic	A/CONF.104/SP/2
Maldives	A/CONF.104/SP/4
Nepal	A/CONF.104/SP/8
Samoa	A/CONF.104/SP/6

holdings, disincentives for share-croppers to use modern inputs and absentee landownership.

With regard to the supply of irrigation water, several public agencies share the responsibility for water control, drainage and irrigation over an area of about 4 million acres. In addition, the private sector accounted for almost 1 million acres of irrigated land in 1980. The current Plan makes provision for an allocation of about Tk30 billion to irrigation and water resources development. The area under irrigation is to be increased from 3.6 million acres at present to about 7.2 million acres by the end of the Plan period. Provision is also made in the Plan for flood control and drainage programmes. It is contemplated that the private sector will play a bigger part in the development of the country's water resources than in the past.

BHUTAN

Energy. Bhutan is endowed with vast--but as yet largely unexploited--water resources, capable of being harnessed for generating larger quantities of hydroelectric power in a region offering a ready market (if exports to India are included). In order to tap this potential source of energy and to halt the over-exploitation of the forests by the local communities (which use wood for fuel) and to make ample supplies of cheap energy available for industrial purposes, it is proposed: (i) To augment generating capacity through the installation of hydro-electric plant; (ii) To build a national grid of power transmission lines; (iii) To reduce the use of non-renewable sources of energy by other sources.

The principal constraints affecting the achievement of these objectives are: (i) The lack of surveys and feasibility studies; (ii) The lack of technical know-how; (iii) The lack of maintenance and repair facilities.

A total budget of close to Nu 200 million has been allocated for the execution of the energy programme under the Fifth Plan. The electricity generating capacity is to be almost quadrupled from the present 4.4 MW to 16.5 MW, investment being estimated at almost Nu 170 million. The construction and/or extension of the network of electricity transmission lines will take place progressively in the course of the Plan period, at an estimated cost of Nu 39 million. Research, development and studies (including studies of the potential of non-conventional sources of energy) are expected to account for a total expenditure of Nu 16 million. In addition, Nu 18 million is to be spent on rural electrification during this period. *N.B.* The Chukha hydroelectric project (cost: Nu 1,130 million) is financed by the Government of India and is not included in the FYP outlays.

Agriculture

For purposes of irrigation, repair of irrigation channels, flood control, erosion control, expenditures totalling about Nu 107 million are envisaged. An additional sum of about Nu 14 million will be invested in an irrigation project in southern Bhutan, largely financed by UNDP and WFP and a grant from the CDF. Furthermore, an agricultural development project will be undertaken in four valleys under an agreement with IFAD, at a total cost of Nu 40 million, of which Nu 35 million is to be provided by external assistance.

LAO PEOPLE'S DEMOCRATIC REPUBLIC

Energy. The country's principal potential source of energy consists of the as yet largely untapped supplies of hydroelectric power. The existing installations have a productive capacity of about 130 MW; the internal demand amounts to 20 MW, the balance is exported to Thailand. With progressive economic development, the internal demand is expected to rise to 180 million kWh by 1985 (exports will decline accordingly). For the purpose of satisfying future demand for electricity (internally and for export), a number of projects for harnessing water power and transmitting the electricity generated are planned (some of them long-term) for the next 20 years, at a total cost equivalent to about $US 650 million. A separate project, worked out by the Mekong River Basin Development Committee for the World Bank, provides for the electrification of the Se Bang Fai plain and for irrigation; the foreign financial assistance for this project is estimated at $ 3.5 million.

For the purpose of training specialists in irrigation and hydroelectric engineering it is proposed to establish a school at Vientiane from which 20 persons would graduate annually. The external assistance required for this project is estimated at $ 1 million, spread over the next four or five years.

Public works. Among the projects planned are the following: (i) sewerage of the city of Vientiane; the estimate of external assistance sought is $ 9 million; (ii) supply of drinking water; the estimate of external assistance sought is $ 6.5 million; (iii) uninterrupted water supply in certain areas; the estimate of external assistance sought is $ 750,000.

Agriculture. Flood control is included among the areas for action projects in this sector.

MALDIVES

Health. For the purpose of achieving the objectives of the Country Health Programme, the Government is to emphasize the provision of primary health care, through better sanitation, immunization and other means. Existing projects, some of which are supported by UNICEF and UNCDF, concern (among other things) the water supply, sewerage, regional hospitals or dispensaries, the control of tuberculosis, leprosy and malaria, the supply of medicines and the training of health workers. In support of these projects, for which the estimates of expenditure are preliminary (and do not cover the cost of training abroad), it is thought that the external financial assistance which will be required in the current five-year period will be of the order of $US 2 million. Other health projects proposed to be undertaken in the course of the next four or five years would be concerned with infrastructure development, nutrition, the supply of essential drugs, etc., and would involve expenditure of which the foreign financial aid element would amount to about $ 1.75 million. In addition, a number of projects are provisionally envisaged in the health field for which external financial assistance estimated tentatively at $ 2.2 million would be needed.

NEPAL

The country's principal natural resources are the land, forests and water. Some mineral resources (e.g. lead, zinc, phosphates, and limestone) are known to exist but are not yet being worked commercially. The primary source of energy is fuel wood, estimated to account for almost 90 per cent of total energy consumption, at a heavy cost in terms of deforestation and soil erosion. The water resource potential is extensive, both for irrigation and for the generation of hydroelectric power. The existing hydroelectric plants have an installed capacity of only 68 MW, expected to rise with the construction of additional plants to 213 MW by 1985. The hydropower potential for long-term development is estimated to be as high as 83,000 MW.

Nepal's potential for development lies, first, in increased production and productivity; secondly, in the exploitation of its water resources for power and irrigation; and, thirdly, in the development of the non-farm sector, including production for exports, with specific emphasis on power, industry, construction, and tourism. To support the increased activity in these various sectors, the health, educational and other social services will have to be expanded and improved.

The objectives of the sixth plan (1980-1985), as approved by the National Development Council are: (i) To increase production at a faster rate; (ii) To increase productive employment opportunities; and (iii) To meet the minimum basic needs of the population (food, firewood, drinking water, health services and sanitation, education, transport).

Agriculture. For purposes of the development of agriculture and in particular of helping the farmers who cultivate small plots or marginal land to increase the production of food crops, the Government is undertaking an ambitious scheme to expand the area under irrigation, using both underground and surface water. Under the Sixth Plan the Government has allocated about NRs 3,310 million ($US 261 million) to this purpose, including meteorology. It is estimated that the foreign financial and technical assistance (including feasibility studies, surveys, engineering design, etc.) required to carry out the irrigation programme will amount to about $US 170 million in the current five-year period.

Health. As part of its policy of meeting the basic needs of the population and of controlling water-borne diseases, the Government intends to provide safe drinking water to the greatest possible number of localities and to improve sewerage and sanitation. An ambitious ten-year programme has been launched in order to achieve these objectives. For this purpose the Government has allocated NRs 1 billion ($US 83 million) under the Sixth Plan; the foreign aid that will be needed in the period 1980-1985 in support of the national programme is estimated at $US 63 million.

Energy. The policy of the Government is to invest heavily in projects for harnessing Nepal's abundant water resources for the generation of electric power (as well as for irrigation). At present, there is a large unfilled demand for electricity, the electricity supply is erratic and industry is hampered by the inadequacy of the power supply. In 1978/79 there were fewer than 100,000 registered consumers of electricity less than 4 per cent of the population benefited from electricity supply; consumption of electricity was only 14 kWh per person in 1979/80. In addition, the regional distribution of electricity is unbalanced. At the moment, fuelwood is the principal source of the energy used for cooking and heating.

The Sixth Plan provides for a large increase in investment in hydroelectric generating stations and in electricity transmission and distribution systems. It is envisaged that 23 existing hydroelectric projects will be completed and that 18 new ones will be started and completed during the Plan period. By 1984/85 total installed generating capacity is to reach 213 MW. It is estimated that about NRs 3,800 million ($US 317 million) will have to be invested in electricity generation and transmission schemes during the period of the Sixth Plan. The foreign assistance required for these purposes during that period is estimated at $US 240 million.

SAMOA

Energy. The Electric Power Corporation (EPC), Samoa's sole producer of electricity for public sale, has a total capacity of 11,399 kW, of which over 85 per cent is diesel-based, the remainder being hydroelectric. EPC accounts for about half of diesel fuel imports. In order to reduce Samoa's dependence on expensive fuel imports and to expand the area served by electric power, with the object of making life in the rural areas more attractive, it is proposed to step up the use of hydroelectric resources and of wood for generating electricity and to extend the transmission network to the rural areas. The total investment to be made in existing or planned projects in the electric energy sector (hydroelectric schemes and thermal power plants) in the course of the current quinquennium is estimated at about $US 37 million, of which about $25 million from external sources. In addition, a large reservoir is to be built, at a cost of almost $70 million, for accumulating the water during the rainy season and releasing it during the dry season.

Water supply and sanitation. Samoa possesses adequate water resources for the urban area of Apia, but in the rural areas supplies of water fall short of the desired quantity and quality. A number of projects are planned in order to remedy this state of affairs. In addition, because the existing systems of drainage and waste disposal are insufficient (particularly in the densely settled urban area), it is proposed in the current plan to begin work on a sewerage system for the Apia area. The cost of the water supply and sewerage systems is estimated at about $11 million, of which about $5.26 million is expected to come from external sources.

Irrigation in Lao People's Democratic Republic: a brief note on current development activities

The Irrigation Department is responsible for the development of irrigation in the Lao People's Democratic Republic. The Department complements its irrigation activity with ground-water investigations for irrigation and drinking-water purposes. Part of the Ministry of Agriculture, Forestry and Irrigation, the Department utilizes the services of a study bureau for survey and design work, and two construction companies for execution of projects.

The irrigation target under the first national five-year plan (1981-1985) is divided into three groups, according to implementing agency. The total planned goal is an additional 85,000 ha of irrigated area (during the growing season) by the end of 1985, as listed here. Most of the 24 projects making up the total effort are receiving external assistance through multilateral or bilateral agreements. There are 16 projects with multilateral components being co-ordinated by UNDP and 8 projects with bilateral components, representing a total input of $US 37 million. Additional agreements cover exchange visits, technical assistance and training directly related to these projects.

Besides increasing the availability of irrigation water, other aims are served to varying degrees among the different projects: flood control and drainage, aquaculture, demonstration farming, vocational training, and operation and maintenance of equipment.

Project type	*Irrigated area**	*Implementing agency*
Medium-large in scale	12,820 (6,770)	Irrigation Department
Small-scale	37,180 (23,230)	Provincial governments
Co-operative	35,000 (2,000)	Farmers' co-operatives
Total:	85,000 (32,000)	

Note: * Figures are given in hectares (ha). Figures in parentheses refer to area irrigable during the dry season.

Currently, co-operative irrigation systems cover an area estimated at 100,000 ha, and small-scale systems cover an additional 15,000 ha. In the areas under co-operative irrigation there is generally one crop per year, since most of the systems are fed by low-flow or ephemeral streams. Small-scale systems receive water from perennial sources, supplemented by pumped water during the dry season or when flow levels are low. Hence nearly half the area served by small-scale systems is double-cropped.

Ground water. The Irrigation Department has embarked on a ground-water survey and development programme in four provinces: Vientiane and Savannakhet (Ground-water Region No. 1), and Luang Prabang and Khammouane (Ground-water Region No. 2). The initial phase of the work covers the Seno area (Savannakhet) and the Vientiane Plain. The project will look into the feasibility of tapping ground water for irrigation and drinking water in drought-stricken areas and localities far from perennial streams.

RURAL WATER SUPPLY SEMINAR IN SWEDEN SETS THE STAGE

At the beginning of the International Drinking Water Supply and Sanitation Decade, a seminar on rural water supply chalked out the key issues in integrating water supply in rural development programmes.

Held at Uppsala, Sweden, in October 1980 for representatives of developing countries and intergovernmental organizations, the Interregional Seminar on Rural Water Supply focused on the following issues in approaching rural water-supply problems: (a) social and economic aspects, (b) planning and implementation, (c) operation and maintenance, (d) institutional aspects; (e) project execution and evaluation; (f) education, training and research.

The Seminar attempted to place these issues in the perspective of rural development programmes. The technological options available to policy-makers was an important point of reference in relating the issues to the task of designing viable programmes for the Water Decade.

Launched on 10 November 1980, the Water Decade is an outgrowth of a recommendation from the United Nations Water Conference held at Mar del Plata, Argentina in March 1977. The Mar del Plata Plan of Action embodies the recommendations and resolutions of the Conference, which cover a wide range of development objectives regarding water resources. The Decade itself is aimed at ensuring safe water for drinking and sanitation purposes for all by the year 1990.

Timed for the beginning of Decade planning activities among developing countries, the Seminar was intended as a Swedish contribution to the Decade, and was funded under a grant by the Swedish International Development Authority (SIDA). It was organized by the University of Uppsala (on behalf of the Swedish Government), and the United Nations Department of Technical Co-operation for Development (DTCD). A report of the activities of the Seminar has been published by DTCD (*Rural Water Supply*; TCD/SEM/81/1), and the proceedings are to be published under the aegis of the Swedish organizing committee. Accompanying this note is an excerpt from the account of the Seminar published in *Natural Resources Forum* (vol. 5, No. 3, July 1981), entitled "Water supply and sanitation" by Enzo Fano.

Choice of appropriate technology

The appropriateness of technology is to be considered in reference to existing natural conditions, existing economic conditions and the human factor. Under difficult natural conditions such as hard rock, there might be no choice as regards technology to be used to develop groundwater, that is expensive, sophisticated and imported equipment. The obligation to carry out a large-scale programme within a limited period of time may also lead to the choice of more advanced technologies.

Under more favourable conditions, there might be more economic solutions that would be more desirable than sophisticated technologies and imported materials. Thus, it may be desirable to consider the following possibilities:

(a) Improving existing traditional construction methods; for example, providing better lifting devices in the digging of open wells, better lining systems and better methods for digging under water;

(b) Using local materials as far as possible. These might include stone, bamboo, trunks of palm trees and so on, or equipment which can be manufactured in the country itself, including PVC pipes or hand-pumps such as the India Mark II;

(c) Last, but not least, the technology should be adapted to the population: its needs, its resources, its cultural level and habits. Rural water supply installations are expected to be utilized to meet real needs and to operate continuously. In particular, maintenance and operation should be uncomplicated and inexpensive. It was recognized that a substantial proportion of project failures is due to wrong choice in selecting the technologies to be used.

A consensus was reached on the following points:

(a) Low-cost technologies, especially those which are imported, are not necessarily economical or appropriate to serve the rural poor.

(b) A certain level of standardization is required in rural water supply systems if efficient management is to be achieved.

(c) Research and inventiveness at the local level should be encouraged.

(d) Local industries for the manufacture of hand pumps, pipes, simple excavating devices and other equipment involved in rural water supply should be developed with a view to increasing self-reliance.

Operation and maintenance

The discussion focused upon the conditions which are to be met to arrive at a satisfactory level of operation and maintenance for rural water supply installations. At the planning stage, any large scale rural water supply programme should include an item for operation and maintenance of equipment and facilities. The size of the resources which are necessary to secure the continuous functioning of one hand pump for one year is in the range of 40 to 50 per cent of the cost of the pump itself. It has happened too often that governments have embarked on large scale rural water supply programmes without being aware of this essential consideration.

These resources should be made available through an independent fund. They may originate from government subsidies intended to benefit the rural poor, or specific benefits arising from the sale of water to industries and rich urban areas. Modest or symbolic contributions might be made by the water users in rural areas, which would motivate them to use installations with proper care. In several cases, however, such contributions are considered unjust, unfeasible and unacceptable by the governments and by the rural population. Finally, it is hoped that external assistance would be forthcoming in the form of equipment, supplies, spare parts.

A specialized organization for operation and maintenance should be established, separate from those dealing with well drilling, construction and pump installation. The organization should not be too centralized (especially if the country is large) with initiative and sufficient means of action at the village and the district level. The organization should be set up before or during the construction phase with sufficient instruction at the village (mechanic) and district (workshop) level, including means of transport (motor-bike or vehicle). Adequate procedures should be provided with the necessary flexibility especially as regards procurement, including purchase of spare parts in foreign currencies. Qualified personnel are needed at the village and district levels in sufficient numbers, but not so overqualified as to contribute to a brain drain.

Operation and maintenance will be facilitated if simple and sturdy equipment and adequate construction methods have been selected; well adapted and simple tools are used, and equipment is protected against misuse and vandalism. Spares and simple tools should be readily available and the population should be motivated to help keep the installation in working order. Simple operations manuals with clear illustrations will assist with the latter goal.

Role of monitoring and evaluation

The importance of monitoring and evaluation was stressed especially as regards the least developed countries. In these countries which have scarce resources, any mistake made in development projects may have very serious consequences. Accordingly, funds should be set aside by project planners for proper monitoring and evaluations, and donor organizations should see to it that such provision has been made within the framework of proper follow-up activities. A specialized unit should be established to carry out these checks, and it should be responsible to the highest level of management. Monitoring and evaluation should be carried out as a continuous exercise, much like maintenance. There should be no acceptable reason or excuse to limit or stop its implementation.

At present, however, such conditions are far from being met. Monitoring and evaluation are omitted in many rural water supply projects for a variety of reasons. One is that unsatisfactory performance is the direct result of improper operating and maintenance practices. This makes it extremely difficult to identify errors in planning, design and execution.

Monitoring should be undertaken in an organized manner. Data on project results should be collected so as to facilitate a continuous check on the following aspects: project efficiency, suitability or planning and design; level of implementation, operation and maintenance; adaptability to load conditions; results achieved in training and upgrading of man-power capabilities.

In addition, specific studies are necessary to assess the positive impacts of the projects in several important areas. Among these are social welfare and human dignity (for example the improvement of living conditions for women); the type and level of water use per capita (increase in water consumption); and health conditions (elimination of water borne diseases).

It has to be noted that the monitoring of health conditions is an extremely difficult operation. There is, of course, an overall feeling that the use of tubewells and pumps has a positive effect on health and that, as a result, life expectancy, especially that of young children, is increased. However, there is thus far no scientific evidence which makes it possible to establish this as an indisputable general truth.

Studies are also needed to assess the negative impact of rural water supply projects, if any, and to define corrective measures. Evaluation exercises should

be carried out by third parties, as implementing organizations may be biased. These evaluations should be based on an integrated approach encompassing technical, economic, social and other aspects.

The purposes of undertaking an evaluation of a rural water supply project are several. The primary goal is to assess whether the project is working: namely that water is produced at the levels of quantity and quality which were expected and that it is available to consumers who use it effectively. In other words, that the objectives of the project have been reached and that they were not lost or altered over time. It is also important to assess the economic, social and other benefits of the project, whether expected or not...

Consumer-producer-donor relationships

Problems and difficulties in the donor-producer relationship were identified as follows: in some countries assistance in water development is provided by a large number of donor organizations which makes planning co-ordination extremely difficult. While this assistance is multiple, it is generally largely insufficient. It is often provided with strings attached, such as the obligation to utilize certain contractors, equipment and supplies, which are not necessarily the most adequate or economic. As a result, the effectiveness of the projects may be reduced. Frequently, too much is requested from developing countries, and especially the least developed, to reach the objectives of the Decade. It is clear that the goals of the Decade cannot be met unless the industrialized countries and OPEC increase their contributions and share of responsibility significantly. Donor organizations sometimes offer 'turn-key' projects, which may be a source of operation and maintenance difficulty due to their unnecessary complexity and sophistication and which deprive local technicians of an opportunity to be involved in the different aspects of project execution.

In the course of the discussions, it was proposed that the donor organization consider providing help according to a number of principles. Aid, when provided in the form of equipment, should fit into the countries' standardization and self-reliance policies. If funds are donated, they should be followed by proper monitoring arrangements. Aid should be development oriented, and it should be utilized as far as possible to promote local industries for the manufacture of pipes, pumps and other products for water supply projects. Donors should be aware of financial constraints and limitations of developing countries and should not request unrealistic counterpart contributions.

Among the problems in the producer-consumer relationship, that of water payments appeared to be the most delicate. It was recognized that water charge systems should be flexible and diversified according to the various types of service provided and of consumers served. The producer should be at the service of the consumer; the government should provide subsidies to cover the costs of the water given to the rural poor. Engineers should have received some training in administration practices, and they should have good contacts with local water committees. The organization of a public relations office, as has been done in several countries, may be of great help in assisting in the establishment of village water committees with the objectives of: popularizing a national water policy, appointing or dismissing pump attendants, assessing water tariffs, collecting revenues and obtaining contributions in cash (for operation and maintenance).

The dialogue between producer and consumer should be constant and open from the earliest stages of project planning, through the construction phases, up to maintenance and operation activities. In particular, consumers should be consulted on problems which affect them. Wherever they are ready to participate in operation and maintenance costs, producers should encourage the design and implementation of development projects. If the matter of the identification of priorities arises, it may be useful to bring donors into the consumer-producer dialogue.

In conclusion, the exchange of views pointed out the difficulties experienced by the producer who has to reconcile the offer made by the donor with the needs and requests of the consumer, taking into account his own resources and capabilities.

Water and "the Bank"...

excerpts from an interview with World Bank water and waste-water adviser John M. Kalbermatten, by American Water Works Association publications director Joseph A. Zullo

What is the philosophy of the World Bank in making loans to developing countries that want to improve their water supplies?

The World Bank tries to design specific projects that will benefit urban and rural poor alike. The bank has a policy of trying to reach the less privileged population class in a developing country. The old theory of "trickle-down effect"—that everyone will benefit from an improved economy throughout the land—proved inaccurate. Consequently, projects are now designed specifically for the less privileged population classes. For example, some 40 per cent of the beneficiaries of the World Bank water and sanitation loans in 1980 were members of the poverty group.

How much money does the World Bank lend each year for water-related projects?

Until mid-1970s, water supply funding constituted only a small fraction of the bank's total outlay. When water projects became more prominent, funding at the $200 million level became common. Now, annual funding for water and sanitation projects varies from $700 million to more than $1 billion.

Source: *Journal-AWWA*, vol. 73, No. 7 (July 1981), pp. 18,20

CHARTING THE ROUTE TO SRI LANKA'S WATER GOALS

Ambitious plans to fulfil the goals of the Water Decade are afoot in Sri Lanka. The Government has drafted a planning document* for its own programme for the International Drinking Water Supply and Sanitation Decade. The draft plan, which is summarized here, serves as a basis for policy decisions and as a guideline for the international funding that will be needed in implementing the ten-year national water supply and sanitation programme.

The success of the Plan will depend on such factors as the degree of community involvement, co-operation, and liaison between the community and relevant government agencies, strong institutions, adequately trained staff, continuous supervision of Plan activities, and adequate logistical support at local and national levels. The use of incentives, avoidance of cost overruns, and the promotion of in-country manufacture of supplies required by the Plan will also be important in the determination of the success of the Plan.

Goals and objectives

The basic purposes of the Plan are: (a) to mobilize public opinion, generate interest, and promote discussion leading to higher levels of community participation; (b) to provide to the Government and international donors guidelines for resource allocation; and (c) to make recommendations consistent with the over-all development objectives of the Government.

Sri Lanka, with one of the highest physical quality of life indexes, presents a better health picture than many other Asian countries. Nevertheless, diarrhoeal diseases are the second highest cause of death, according to 1976 statistics. Furthermore, in 1977, 66 per cent of the total health budget was devoted to curative care and only 24 per cent was spent on preventive care. The incidence of water-related morbidity is still high in 1980. One important aspect of the Plan is increasing the quality and quantity of health education.

In water supply, the national goal is to improve conditions in quality, quantity, reliability, and accessibility. In sanitation, the Government will introduce vast improvements in urban and rural sanitation. Piped sewerage will be limited to a few cities. Efforts to improve excreta disposal will be co-ordinated with efforts to improve water supply. The emphasis will be on improved pit and water-seal latrines, and the entire effort will be strengthened through increased health education and community participation.

Coverage programme objectives. The Government plans to provide the entire urban population in the country with safe and reasonable quantities of piped water by 1990. It is recognized, however, that all urban systems may not be completed until the mid-1990s. Although the Government will attempt to provide 100 per cent of water needs in the rural sector by 1990, the Plan provides for 50 per cent coverage of the rural population by 1990 and 100 per cent by 1995. The emphasis in the short term will be on the conversion by 1984 of all bucket latrines in the country to either water-seal or pit latrines, preferably the former, whenever and wherever water supplies are available and sufficient. Sanitary excreta disposal in the rural sector will be improved by increasing the number of water-seal and pit latrines, construction of which will be encouraged by Government-provided incentives.

Support programme objectives. Six support programmes have been identified, as follow:

(a) Human resources development: entry-level, mid-career, and advanced-level training will be provided.

(b) Appropriate technology: those industries that use national manufacturing and local operations and maintenance capabilities will be given preference.

(c) Health education: preventive health care will be improved by realigning both human and financial resources.

(d) Community participation: community organization to identify and solve water and sanitation problems and to promote self-reliance will be encouraged in ways which strengthen the community development process.

(e) Institutional change: existing institutions will be strengthened and other changes introduced to achieve national goals.

(f) Financial and investment priorities: revenue collections will be increased; water tariffs will be instituted; low-income consumers of water will be subsidized.

Current water supply and sanitation needs

In 1971, 13 per cent of the total population had access to some piped water, most of this population was located in 66 (out of a total of 135) of the urban communities that then existed. The 1971 census data also indicate that 45 per cent of urban and 5 per cent of rural houses had access to piped water; 75 per cent of estate housing also had access to piped water. However, most of the supplies were deficient in quality and quantity.

* Government of the Democratic Socialist Republic of Sri Lanka, Ministry of Local Government, Housing and Construction, *Plan for the Drinking Water Supply and Sanitation Sector in Sri Lanka for the Decade (1981-1990)*; text from "Executive summary".

In 1977, the data indicated that about half of these schemes produced less than 5 gallons *per capita* per day (gpcd), and that another 40 per cent produced between 5 and 20 gpcd. The remainder had a production of 40 to 60 gpcd. The UNICEF-aided water supply programme had probably increased the percentage of the rural population served by piped systems to at least 10 per cent by 1980. Over 80 per cent of the 1980 rural population draw their water from 1 million privately owned and 19,000 community wells; the remainder draws its water from tanks, streams, and irrigation canals.

The quality aspect of existing water supplies is unsatisfactory in both the urban and rural sectors. Reliability has been affected as service has become intermittent. Existing water sources have become insufficient as populations have grown and water demand has increased.

As far as sanitation is concerned, the 1971 housing census indicated that 23 per cent of urban and 2.2 per cent of rural houses had flush toilets. Fifty-seven per cent of urban houses had water-seal, pit, or bucket latrines, while only 5 per cent of rural homes had these same facilities. Nineteen per cent of urban and 42 per cent of rural housing units had no disposal facilities. Nineteen per cent of the urban population and a smaller percentage of the rural population were served by bucket latrines in 1971. The number of people using bucket latrines in 1980 was estimated at 636,000.

Although very few data are available on the operational status of water supply and sanitation facilities, substandard operations in both are widespread. In addition to broken equipment (e.g. broken chlorinators, gauges, standposts, and diesel and electric pumps), there have been other problems, such as saline intrusion, lowering of the water table, and deterioration of surface wells.

The provision of water supply services is proceeding at a faster pace than the installation of sanitary excreta disposal facilities, primarily because of the lack of

Organization of water supply and sanitation sector in Sri Lanka

Institutional responsibilities under the Plan have been allocated as follow. In addition to the institutions identified here, international donors will be encouraged to participate.

National Water Supply and Drainage Board (NWSDB): major responsibility for urban and non-urban piped water and sewerage; backstopping rural water schemes

Department of Local Government: shallow community wells in rural areas

Ministry of Health: all non-piped sanitation programmes

Ministry of State Plantations, and Ministry of Janataha Estates Development: all programmes in water supply and sanitation in their areas

Ministry of Mahaweli Development: development of all non-piped water supplies; planning only of piped water and sewerage, design and construction of which will be undertaken by NWSDB

Water Resources Board: hydrogeological investigations

Department of Buildings: water and sanitation for Government buildings

Common Amenities Board: Government-owned urban compounds

Functional responsibilities have been identified as follows.

(a) *Investigations and research*: NWSDB, Water Resources Board, University of Colombo Marga Institute

(b) *Project construction*: NWSDB, District Development Councils, Sri Lanka State Plantations Corporation (SPC), Janataha Estates Development Board (JEDB), Mahaweli Development Board (MDB). Co-ordination functions will be provided by the Water Supply and Sanitation Division of the Ministry of Local Government, Housing and Construction, the National Co-ordinating Committee for the Water Supply and Sanitation Decade, various divisions and regional offices of the Ministry of Health on rural sanitation projects, and the community centres

(c) *Operation and maintenance*: NWSDB (all piped-water supply and sewerage); SLSPC and JEDB (water supply and sanitation on estates)

(d) *District Development Councils*: non-piped water supplies in rural areas

(e) *Mahaweli Development Board*: areas under the Mahaweli Project

(f) *Rehabilitation*: for drilled wells, NWSDP; for shallow dug wells, District Development Councils; for Mahaweli areas, MDB; for estates, SLSPC and JEDB

(g) *Training*: training in water supply will be the primary responsibility of NWSDB. The responsibility for training in health education and community participation will rest with the Ministry of Health through the National Institute of Health Sciences and NWSDB. The Ministry of Health will also have the main responsibility for water-quality monitoring.

(a) perception of the need and importance of sanitary excreta disposal and its relation to health; (b) the efficiency of the public health inspectors and the logistic support they need but do not receive; and (c) the organizational emphasis by the Ministry of Health on the construction of latrines.

There are socio-cultural constraints that may affect the results expected from the successful implementation of the Decade Plan. One of the most important constraints is the view that water is a free good, a God-given gift, a right that accompanies land use and property rights over land. The social equities and inequities of alternative policy choices must be given due consideration in the decision-making process of government.

The costs to users of water supply services in 1980 were primarily based on a property assessment tax, ranging from 6 to 30 per cent, that was levied on consumers by the local authority. The insufficiency of the tax base and the resulting low level of revenues, the delinquency of consumers in paying their taxes, the nonpayment of operation and maintenance costs by the local authorities to the National Water Supply and Drainage Board (NWSDB), and the default on national Government-funded loans by the local authorities have exacerbated the financial conditions of the systems, the provision of water supply, and the operation and maintenance of the systems. As far as sanitation is concerned, the Ministry of Health provides a subsidy equivalent to 6 per cent of the total 1980 cost of a latrine. The insignificant level of this financial incentive compared to the total cost and problems in perceiving the need for sanitary excreta disposal have not resulted in an effective programme of increasing sanitary facilities.

One of the most important deficiencies is the operation and maintenance of existing water supply systems. The lack of proper maintenance can be traced to (a) lack of sufficient and qualified staff assigned to maintenance functions; (b) the variety of equipment from many countries and associated problems of procurement and customs clearance; (c) the lack of transport facilities, even when spare parts are available; (d) the lack of permanent technical professionals assigned to the plans for daily process control and technical decision-making; and (e) the heavy emphasis on construction activities which allows only a few staff to be assigned part-time to operational and maintenance activities.

The absence of laboratories outside Colombo capable of conducting water quality analysis and shortages in institutional capabilities and health personnel make the existing activities in this area inadequate and in need of improvements.

In the large number of governmental institutions (see annex to this article) involved in water supply and sanitation, the diffusion of responsibilities has led to bottlenecks which have been exacerbated by the lack of co-ordination between the institutions. Despite recent attempts to improve and increase co-ordination, much more needs to be done.

Policies and strategies for the Decade Plan

(a) *National strategies*

(i) National self-reliance in Decade Plan implementation;

(ii) Mobilization of public sector personnel;

(iii) Mobilization of existing and new human resources;

(iv) Creation of a legal framework for water and sanitation legislation;

(v) Increasing the capability and capacity of the public sector to generate internal and external financial resources for the Decade goals;

(vi) Drinking water supply and sanitation planning strategy for the Decade and beyond:

1981-1984	Mobilization stage
1985-1990	Accelerated action stage, phase 1
1991-2000	Accelerated action stage, phase 2
1982-1984	First evaluation of the Decade Plan
1991-1992	Second evaluation of the Decade Plan

(b) *Regional strategies*

(i) Responsibility, capacity, and effectiveness of regional offices;

(ii) Capabilities and effectiveness of local authorities;

(iii) Developing and strengthening ties between district councils and urban and rural communities;

(c) *Community-level strategies*

(i) Strategy for community participation;

(ii) Development of community leadership resources;

(iii) Use of community water supply and sanitation volunteers;

(iv) Establishment of an assistant district minister in charge of water supply and sanitation;

(v) Accelerated installation of latrines in the urban and rural sectors.

Sri Lanka at this time has a substantial amount of industrial capacity to meet the demand for materials and supplies during the implementation of the Plan. Nevertheless, a strong push for industrial development will be needed, and it must be spearheaded by Government incentives, such as tax concessions, and efforts to make capital resources easily available to the industrial sector.

The total cost of the Decade Plan ultimately will be borne by the Government, international donors, and consumers. Approximately 75 per cent of the capital costs are expected to come from the international donor community, and the remainder from the public and private sectors of Sri Lanka. To attract a maximum of international funding, the Government should consider upgrading its analytical and project management staff in order to ensure a smooth and continuous flow of project documents which could be considered seriously and expeditiously by international donors. Such a priority project would itself be an excellent candidate for international funding.

The Government intends to more than double the budgetary expenditures for water supply from the 2 per cent it budgeted in the past to 4.3 per cent in the 1981-1984 period. This indicates the increasing importance being given to this sector. However, even this doubling will not be sufficient to realize the goals of the Decade Plan if additional local and international funds are not made available.

To improve sector performance, the following programmes are recommended to increase the operation and maintenance capability of NWSDB.

Programme 1: Headquarters strengthening
Programme 2: Regional strengthening, phase 1
Programme 3: Regional strengthening, phase 2

A major rehabilitation effort of existing water supply schemes should be undertaken by the Government during the period 1981-1984. The development of new schemes will be undertaken in three phases; summary tables of coverage programmes in water supply and sanitation are given as follows.

The major sector inputs for the implementation of the Plan are human resources and staffing, training, water quality monitoring, and selection of appropriate levels of technology.

Total investment in water supply coverage programmes (in million rupees)

	Years	*Urban*	*Rural*	*Estates*
	1981-1984	1 956	1 191	363
	1985-1990	3 427	1 630	492
	1991-1995	–	1 630	–
Total	1981-1990	5 383	2 821	855
Total	1981-1995	5 383	4 451	855

Total investment in sanitation coverage programmes (in million rupees)

	Years	*Sewerage*	*Bucket latrine coversions*	*New latrines*
	1981-1984	1 372	169	1 315
	1985-1990	408	–	1 974
Total	1981-1990	1 780	169	3 289

Coverage programmes directly extend the coverage of water supply and sanitation services to the populace; the support programmes are those activities used to minimize the constraints involved. Thus, the support programmes in the Decade Plan will develop the human and physical infrastructure that is needed to implement the coverage programmes. The estimated cost summary, by type of support programme, is given here. Detailed information and analysis of the costs can be found in the annexes of the main report.

Type of support programme	*Cost (in million rupees)*
Infrastructure for training	135.43
Training support programmes	73.50
Community participant support programmes	30.00
Maintenance management support programme	2.00
NWSDB institutional strengthening	163.88
Ministry of Health institutional strengthening	6.60
Local authorities institutional strengthening	22.00
Total	433.41

The anticipated total costs of all support programmes in the Decade Plan phased throughout the 10-year period are given in the table on the following page, which is taken from volume one of the main report.

The foregoing table presents a more detailed breakdown of support programme costs than does the previous table, because it includes the local and foreign exchange funding requirements.

To avoid overloading public sector investments in the short run for the implementation of the Decade Plan, investment requirements for the 1981-1984 period have been kept to reasonable and conservative estimates. This mobilization period puts special emphasis on support programmes without which the remaining coverage activities could not achieve the desired and expected results. The participation of international donors has been estimated at 75 per cent of total resource requirements in water supply investments and 47.5 per cent in sanitation. Local public sector contribution in water supply investments has been estimated at 25 per cent, while for sanitation, the public sector share--in the form of a subsidy provided by the Ministry of Health--has been estimated at 12 per cent of the total; the contribution of the head of household has been estimated at 40.5 per cent. Grants from international donors for the conversion of bucket latrines to pit and water-seal latrines during the period 1981-1984 have been encouraged.

Anticipated total costs of all support programmes in the Decade Plan

(in million rupees)

Year	Institutional development			Operation and maintenance			Sector infrastructure and construction			Community participation			Training			Water quality monitoring			Annual totals		
	T	D	L	T	D	L	T	D	L	T	D	L	T	D	L	T	D	L	T	D	L
1981	9.29	8.87	0.42	5.98	5.59	0.39	21.71	21.32	0.39	4.25	4.25	0	35.13	35.13	0	0.66	0.63	0.03	77.02	75.79	1.23
1982	10.94	10.11	0.83	5.55	4.76	0.79	24.57	23.79	0.78	3.50	3.50	0	36.96	36.96	0	0.80	0.73	0.07	82.32	79.85	2.47
1983	-	-	-	-	-	-	-	-	-	4.75	4.75	0	27.93	27.24	0.69	-	-	-	32.68	31.99	0.69
1984	-	-	-	-	-	-	-	-	-	5.00	5.00	0	29.50	28.12	1.38	-	-	-	34.50	33.12	1.38
1985	8.71	8.50	0.21	6.63	5.97	0.66	38.15	37.50	0.65	5.00	5.00	0	23.68	21.61	2.07	0.70	0.68	0.02	82.87	79.26	3.61
1986	9.55	9.13	0.42	10.25	8.94	1.31	39.45	38.15	1.30	3.75	3.75	0	12.98	10.20	2.78	0.81	0.77	0.04	76.79	70.94	5.85
1987	-	-	-	-	-	-	-	-	-	2.50	2.50	0	12.20	10.15	2.05	-	-	-	14.70	12.65	2.05
1988	-	-	-	-	-	-	-	-	-	1.25	1.25	0	10.42	7.49	2.93	-	-	-	11.67	8.74	2.93
1989	-	-	-	-	-	-	-	-	-	-	-	-	10.39	7.39	3.00	-	-	-	10.39	7.39	3.00
1990	-	-	-	-	-	-	-	-	-	-	-	-	10.47	7.39	3.08	-	-	-	10.47	7.39	3.08
Decade totals	38.49	36.61	1.83	28.41	25.25	3.16	123.88	120.77	3.09	30.00	30.00	0	209.66	191.60	17.98	2.97	2.81	0.16	433.41	407.12	26.29

Note: T = total cost; D = donor cost; L = local cost.

The ten-year investment plan, 1981-1990

The investment plan has two broad categories: support programme investments and coverage programme investments. They include the following.

Support programmes

Institutional development

Operation and maintenance

Sector infrastructure and construction

Community participation

Training and human resources development

Water quality monitoring

Coverage programmes

Urban water supply

Estate water supply

Rural water supply

Urban sewerage

Sanitation

The total investments needed for all support programmes during the Decade are estimated at 433.4 million rupees. Foreign and local sources are expected to provide 407.1 million and 26.3 million rupees, respectively.

The total of coverage investments for the Decade was estimated at 14,298.5 million rupees. Adding the investments needed for 1981-1985, the grand total of coverage investments was estimated at close to 16 billion rupees. A summary of the support and coverage programme investments is given here.

Summary of national investments in water supply and sanitation for the Decade Plan

(in million rupees)

	1981-1984	*1985-1990*	*1981-1990*	*1991-1995*	*1981-1995*
Coverage programmes					
Water supply	3,510	5,549	9,059.91	1,630.25	10,690.16
Sanitation	2,856	2,382	5,238.55	-	5,238.55
Total coverage Programmes	6,366	7,931	14,298.46	1,630.25	15,928.71
Support Programmes	226.52	206.89	433.41	-	433.41
Total Plan	-	-	-	-	16,362.12
Total Decade	-	-	14,731.87	-	-

UNESCO HYDROLOGICAL ACTIVITIES

Regional water log, January-June 1981

The UNESCO Regional Office for Science and Technology for South-east Asia has reported on its water-related activities during the first half of 1981, together with other scientific and technological activities in the region, following the guidelines and programme themes outlined in the foregoing paragraphs.

(a) *Regional Training Seminar on Urban Storm Water Management (Manila,* 13-21 March 1981): organized by WMO, in collaboration with UNESCO and ESCAP, and funded by UNDP. The 30 participants came from Bangladesh, China, Hong Kong, Malaysia, Pakistan, the Philippines, the Republic of Korea, Sri Lanka, Thailand and Viet Nam. The participants were generally drawn from national meteorological services and national water resources agencies. The Seminar was comprised of lectures, tutorials and a field visit, and each delegation presented a country paper.

(b) *Water Resources Assessment Project in Indonesia.* The various institutes contracted for this project were compiling all available data on incoming global solar radiation, duration of bright sunshine and pan evaporation. After the data are compiled, the relationships between these parameters will be studied. This first project is likely to lead to studies of other components of the water balance.

(c) *Aquatic weeds.* Dr. P. Edwards of AIT was contracted to study the problems relating to water hyacinth and its management, and the opportunities for composting water hyacinth to produce fish-pond fertilizer. He visited several institutes, related research projects and sites of interest in west and central Java, Indonesia. He made a report based on work currently being done in Indonesia, Thailand and elsewhere in Asia.

(d) *Glossary of hydrology.* The preparation of a glossary of hydrology and hydrogeology in the Indonesian and Malaysian languages is proceeding, based on the UNESCO/WMO *International Glossary on Hydrology* and on the UNESCO *International Glossary of Hydrology.* The two committees of experts held three joint meetings, one in Malaysia and two in Indonesia. UNESCO is providing financial support for travel to those meetings. It is hoped that the preparation of this glossary will lead to a joint textbook and increased co-operation in research.

(e) *Roof runoff project.* This study on the reliability of roof runoff for village water supply has been completed by the Bogor Agricultural Institute. The report, in English, outlining the techniques used in the study has been prepared for distribution in the region, as is the report in the Indonesian language, detailing the hydrological design of roof runoff systems for selected areas of Java, Madura, Bali and Lombok.

(f) *Training course on ground water.* The course is being jointly organized by UNESCO and is to be held at the Institute at Bangkok in December 1981.

THAILAND'S FIRST WORKSHOP FOR THE WATER DECADE

Decisions for a decade of water development

Thai efforts to realize the water supply and sanitation goals of the 1981-1990 Water Decade have made an energetic start with the results of a national workshop, held at Chiang Mai, 22 to 27 June 1981, with WHO support. The First National Workshop on the International Drinking Water Supply and Sanitation Decade brought together high-ranking policy-makers, experts and administrators from the host of Government agencies* which collectively manage Thailand's water resources, from universities, and from international agencies and foreign Governments which are aiding the Thai effort. The following account of how the Thai plan is shaping up has been extracted from the English version of the final Workshop report.

* Including the National Economic and Social Development Board (NESDB), Budget Bureau, Provincial Water Works Authority, National Security Council, Department of Mineral Resources, Department of Local Administration, Department of Health, Department of Public Works, Royal Irrigation Department, Community Development Department, Land Development Department, Department of Technical and Economic Co-operation, Office of Accelerated Rural Development, Office of Policy and Planning (Ministry of the Interior), Committee for the Co-ordination and Promotion of Water Resources Development, Sub-committee on Water Resources Planning; among others.

Planning framework for the Decade

Strategies and priorities for a national plan emerged from the Chiang Mai Workshop, as well as the determination to co-ordinate action in preparing the detailed plan and designing an action programme. The National Economic and Social Development Board (NESDB) is the central co-ordinating agency for developing the Decade work plan. The Sub-committee on Water Resources Planning within NESDB serves as the focus for activity in the formulation of a national policy on water resource planning.

In his opening address at the Workshop, the NESDB Secretary-General Dr. Snoh Unakul stressed the importance of provision of water supply and sanitation in combating poverty and raising living standards especially in rural areas. "NESDB, as a focal point for the Decade work, has accomplished and/or plans to implement the following" actions, according to Dr. Snoh.

"A working group, responsible for drafting a Decade work plan for inclusion in the fifth national development plan [1981-1986], has been organized and its report has been submitted to NESDB for consideration and to have it incorporated in the rural development plan. In the fifth plan, emphasis will be made on provision of water for domestic use along with safe drinking water. Improvement of water quality will be emphasized in the sixth plan [1986-1991].

"On institutional arrangements, NESDB will first improve its own capability to be able to function effectively as a focal point for the Decade. A centre for operation planning, evaluation and co-ordination will be established to oversee the plan implementation. NESDB will review the organization and the responsibilities of the implementing agencies at the central, provincial and community levels. NESDB will define clearly responsibilities of the implementing agencies in the construction, operation and maintenance, provision of budgetary allocation and also in carrying out monitoring and evaluation. These activities will be under the supervision of one organization. If deemed necessary, a water resource planning board may be created to take up these responsibilities.

"In addition to the on-going programme of safe drinking-water supplies and sanitation, which will continue during the fifth plan period, NESDB has also included, in the Office of Accelerated Rural Development project, water source construction and supply of safe drinking-water; and, under rural development in the poverty areas, has also included such a programme to be implemented by Department of Health with an allocation of about 500 million baht in the fifth plan. A project is also being formulated for data collection, monitoring and evaluation of the Decade work during the fifth plan.

"The success of the Decade plan depends on the appropriate technology used, understanding and acceptance of the people, and in particular, community involvement in the maintenance of the systems when construction is completed. This requires training at the middle and lower levels." Dr. Snoh emphasized that water and sanitation facilities are basic amenities which the Royal Thai Government is committed to provide to the people as soon as possible, so that human resources can be utilized in national economic and social development as well as for the security of the country.

Complementing the briefing on over-all strategy from NESDB, the Deputy Director-General of the Health Department contributed some remarks on the action programme of the Ministry of Public Health. The Ministry had gradually shifted its priority emphasis from medical care to preventive care. In the fifth plan, five such projects were included under the health development plan: on potable water, environmental health, food hygiene, community and hospital waste disposal, and environmental pollution control. An essential component in ensuring the success of these projects was community involvement. In this connexion, the Deputy Director-General offered the following reminders.

- Health education and social preparation should come first;
- Remember that villages have some experience and know how to adapt;
- Support community needs, but do not simply satisfy the needs as assessed by Government officials;
- Co-operate with villagers, not the other way around;
- Encourage a sense of ownership among villagers;
- Respond to community needs as far as feasible.

The total manpower related to water resources development for fiscal year 1981 is 128,701 persons, of which 27,941 are regular Government officials, 32,449 are permanently employed personnel and 68,311 are temporarily employed personnel.

Overview of the needs and priorities

Only 64 per cent or 24.2 million people in the rural areas currently have access to water sources provided by the Government. It has been estimated that by 1990 the rural population will have increased to around 44.2 million. Thus during the Decade, provision of water for drinking and domestic uses will need to be made for an additional 20 million people.

The Department of Mineral Resources contributed to the Workshop a paper on rural water supply in

Thailand and an outline of a programme for the fifth national development plan.

The Government spent an estimated SUS 20 to 25 million per year during the fourth plan period (1976-1981), according to an ADB report delivered at the Workshop. The report said that up to 1978, more than half of the total expenditure was on deep wells, about 15 to 20 per cent on piped water supplies, and about 5 per cent on small ponds, dredged ponds from swamps, small dams and dykes. Provision of shallow wells, which in many areas of Thailand appear to be viable water supply sources, and the protection of existing wells seem to have attracted less attention, with about 5 per cent of the expenditure devoted to these types of works. In 1978, the National Institute of Development Administration concluded that perhaps as little as 10 per cent of the population had access to safe drinking water, and one third of the rural population had access to water-seal toilets and pit latrines.

Based on cost-effective systems and the assumptions that the installed facilities would be maintained and used, ADB estimated that the total resource requirements from the Government and other external sources were on the order of about $70 million per year, or about three to four times what is now being spent in this sector.

The Workshop discussed the major problem areas and strategies for resolving them. Some of its key conclusions are outlined in brief form as follows, regarding strategies and targets, as given in the Workshop report.

1. ***Policy, measures, strategies to achieve Decade targets***

(a) *Policy*

(i) To provide adequate drinking and domestic water for all;

(ii) To provide basic sanitation for improved health;

(iii) To encourage community participation in Decade activities in every way, e.g. water quality improvement, construction, repair and maintenance;

(b) *Measures*

(i) Prepare a master plan for Decade activities;

(ii) Establish central co-ordination unit to analyse data, co-ordinate work plan and implementation,

(iii) Prepare the community to participate;

(c) ***Basic strategy***

(i) Survey existing water resources (quantity and quality) and health status of people;

(ii) Construct and improve water sources;

(iii) Encourage people to build storage jar and tanks for rain water collection;

(iv) Dig protected shallow wells, drill artesian wells, construct small-scale water works;

(v) Encourage private sector to help in Decade activities;

(vi) Follow up, evaluate and revise work plan where necessary;

(d) ***Support strategies***

(i) Train local leaders and volunteers for education/information activities at community level;

(ii) Establish revolving funds for Decade activities;

(iii) Research appropriate technology for different types of localities.

2. ***Establish priorities, targets and the work plan***

(a) Area to be covered

(i) Rural poverty areas as determined in the national plan;

(ii) Water-scarcity areas;

(b) Population groups with greatest need

(i) Safe drinking water is needed by 95 per cent of the rural and 70 per cent of the urban population;

(ii) Basic sanitation is needed by 50 per cent of the rural and 70 per cent of the urban population.

Foreign assistance

ADB reported that its work so far had led to the conclusion that a master plan is needed for outlining the strategies for the successful implementation, maintenance and operation of the new facilities. In the preparation of such a plan, the following considerations should be addressed, according to ADB, and recommendations made on: (a) type of technology employed, (b) role to be played by the beneficiaries; (c) identification of the role of Government agencies; (d) an initial investment programme.

ADB offered assistance in implementing a Thai programme for water and sanitation facilities, once a master plan, is completed. ADB stated at the Workshop that if such a master plan is formulated, and it meets ADB requirements, ADB would be ready to appraise

a loan for construction of water supply and sanitation facilities provided that local counterpart funds could be made available on time. The areas for ADB-financed, high-priority projects would be those identified in the master plan.

In a contribution from another donor agency, a representative of USAID mentioned the long involvement of that Agency in the development of water supplies and sanitation in Thailand. He reported on the results of a recent evaluation of completed works, which concluded that the increased quality of water available for the population has more significant impacts on health than does enhancement of the quality of water. This is especially true in the case of providing sanitary latrines for the population. The USAID representative observed that this conclusion bears on strategy for water supply development activities, and might not meet with the agreement of all donor or lending agencies which are concerned with high-quality as well as high-quantity delivery systems.

The USAID representative also commented on the several types of water delivery systems which are worth considering in the Thai context, as follows.

(a) *Shallow wells*: commonly used in Thai rural areas as a source of water. These are suitable for use if they are well protected against contamination. The installation of hand pumps sometimes fails to give protection in areas where the water table is high and the soil porous. Contamination may also occur during water collection, transport and storage. It is believed that the protection of water sources and installation of hand pumps alone cannot guarantee improvement in the health status of the population if people do not use a great enough quantity of water for their personal needs.

(b) *Deep wells*: suitable as sources of water for rural areas where water is scarce. If hand pumps are installed, the wells will increase the quantity of safe water. However, deep-well water sometimes has a high mineral content, so the wells are seldom used for drinking water by the population. Problems relating to the use of deep wells include the lack of safe transport of water to homes, and breakdowns of pumps owing to lack of maintenance. Current designs of polyvinyl chloride (PVC) hand pumps may substantially reduce the present maintenance problems.

(c) *Rain-water cisterns*: suitable for use as drinking-water sources. As the quantity of water used has to be limited considerably, it may not yield significant improvement in health levels. Cisterns are relatively expensive to build.

(d) *Piped systems*: used to transport water safely from protected water sources to usage points. The systems are usually combined with elevated tanks and (sometimes) with pumps. Initial capital cost for constructing such systems is high, however. They may generate revenues from water users to become self-sufficient in operation. Health and economic benefits can result from piped systems, so that they are justifiable as an appropriate strategy for improving and expanding rural water supplies. Through the use of less costly designs the potential use of piped systems can be improved.

USAID/Thailand reported that it is prepared to sponsor analytical efforts to determine the most cost-effective and culturally appropriate manner in which to increase water availability in Thailand.

Conclusions: the first steps

NESDB cited the principal objectives of national water resources development that were included in the next five-year plan, as follow: (a) to increase agricultural productivity; (b) to meet basic water requirements for domestic use; (c) to reduce the energy deficit in the country; and (d) help in reducing social and economic disparities among the people. NESDB had already taken the initiative in setting up an operations centre to analyse and co-ordinate the programme of the implementing Government agencies.

The Workshop recommended, among other proposals, that NESDB should establish a steering committee and a working group. The steering committee would be composed of senior officials from all implementing agencies, and would be responsible for providing advice and for directing the working group. The working group would be composed of full-time officials from the implementing agencies assigned to work with NESDB during the preparation of the decade work plan. The first six months in the development of the work plan should be devoted to data collection. The data, to be stored in a data bank, would be continuously updated. Either the computer centre at AIT and/or at the Ministry of the Interior would be used.

Existing resources in each province should be relied on in implementing the work plan for the Decade, according to the Workshop. The provincial office, community development officers, village committees and village volunteers are examples of these resources. Attempts will be made to strengthen these resources by providing training programmes as needed. NESDB should consult the Ministry of Interior in strengthening the provincial offices.

NESDB should establish another working group for sanitation. Representatives from the Ministry of Health and the Ministry of Interior would be involved in the development of policies, work plans and structures for matters related to sanitation during the Decade.

DEVELOPMENT AND MANAGEMENT ISSUES

ENERGY AND WATER CONSERVATION STRATEGIES IN IRRIGATED AGRICULTURE

*Ronald L. Ritschard and Karen Tsao**

California's agricultural industry during 1977 experienced a second year of drought conditions north of the Tehachapi Mountains. The resulting water shortages were of only minor concern in southern California and most central coast areas, but were troublesome and costly in the Central Valley. The map of California shown in figure 1 depicts more specifically the varying effects of the drought by area. As shown by the map, the central coast counties and those of the coastal and desert regions of southern California received precipitation that was close to normal. Furthermore, sufficient surface water was available in the southern California area from the Colorado River to eliminate any drought threat to this agricultural region. Other areas of the state, namely the north coast, San Francisco Bay, Mountain and Central Valleys (the Sacramento and San Joaquin Valleys) did not fare as well.

Approximately 9 million acres harvested in California during 1977 were irrigated. Water and energy requirements for irrigation vary widely across the state as a function of the proximity of water sources, soil conditions, the methods of irrigation, and the water needs of the crops. The dry years of 1976 and 1977 present an opportunity to see how farmers met their irrigation needs with limited supplies of surface water. In this study, agriculture's responses to the drought conditions of 1977 are outlined. Because the over-all purpose of this study is to determine if this information can help develop a long-term approach for water and energy conservation in irrigated agriculture, the present and potential conservation strategies applicable to California are identified and presented.

AGRICULTURE'S RESPONSES TO THE DROUGHT CONDITIONS OF 1977

Although the drought-related losses to California agriculture were projected to range from $US 500 million to $1.5 billion, the total state agricultural income was down only about 1 per cent from the previous year (California Department of Food and Agriculture, 1977). Furthermore, an estimated $500 million of the total gross farm income reductions came from the livestock industry, which also suffered from the second year of drought.

Increased use of ground water

During drought periods, the state's most significant source of reserve supply is ground water. In a normal year, ground-water pumping in the state accounts for about 15 million acre-feet (California Department of Water Resources, 1974). It is estimated that 50 per cent of this water results from the recharge percolation of applied surface water, 36 per cent is due to natural recharge, and the remainder is overdrafted from ground-water basins (California Department of Water Resources, 1977). In 1977, ground-water pumping increased by over 20 per cent to compensate for the deficiency of surface water, with an estimated 7,500 new wells drilled in California during the year (California Department of Food and Agriculture, 1977). In addition to the new wells, farmers reactivated old ground-water delivery systems and deepened existing wells. By the end of 1977, ground-water accounted for at least 53 per cent of all water used by agriculture in California, compared with a normal year average of 40 per cent.

The increased pumping of ground water had two immediate impacts: in the Central Valley, where most of the increased pumping occurred, the water table dropped significantly, and the cost of water rose significantly when the costs of drilling new wells and of additional energy used in pumping were taken into account. Drilling new wells cost from $30,000 to $150,000 depending on the size and depth of the well, and energy costs to pump the ground water, especially from the increased depths, can range from $33 to $40, compared to a price of $8.50 to $11 for transporting surface water from a canal.

Increased efficiency of water application

Several strategies to increase the efficiency of water application were used in 1977. Growers practised "cutback irrigation", a management scheme that diminishes runoff and reduces deep soil percolation in furrow systems. The procedure uses a high-volume initial stream to cause rapid water advance down the furrow, and then reduces flow rate subsequently to maintain minimum flow. Some farmers collect excess water at the end of the fields and pump it back to the

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head of the field. This return-reuse method of surface irrigation is regarded as both an energy- and a water-efficient procedure.

Another strategy used to increase the efficiency of water application was the change in irrigation methods. There was an increase in the installation of sprinkler and drip systems. These changes involved large expenditures of capital and certain delays due to the time needed to design, order, and install the new irrigation systems. Although a net decrease in water use may have resulted from the use of sprinkler and drip systems, their implementation may increase energy use, depending on the water source that is employed.

"Deficit irrigation", which is simply the application of less water than needed to replace soil moisture loss, was also practised. The application of less water reduces evaporation and transpiration from cropped areas. However, because the relationship between crop yield and water stress is a very critical one, the optimal amount of water to apply to the plant system must be determined very carefully.

Yet another technique used because of water storage was that of "postponed leaching". Leaching is the addition of water beyond that amount needed to replace the loss from evapotranspiration, to balance salt levels in the crop's root zone. Leaching requirements were reduced drastically in some areas of the state. While this saved more irrigation water, the impact of this strategy in the future is unknown because its use is still untested on a large scale and over long periods of time.

Cropping pattern changes in 1977

Although water available from the State Water Project in 1977 was cut back nearly 50 per cent from the previous year, irrigated acreage was reduced only 13 per cent on a state-wide basis (California Department of Food and Agriculture, 1977). That this reduction of irrigated acreage was not more drastic is due to changes in crop patterns, which can result in savings in both energy and water.

The 1977 crop patterns show decreases in acreage for some commodities and increases in others. These changes in California, as elsewhere in the United States of America, are determined by market conditions that are governed by state, national, and international forces, as well as by local weather conditions. Table 1 shows planted acreages of selected crops for the 1975 and 1976 growing seasons along with plantings in 1977. The largest acreage reductions from 1976 were for sorghum (-37 per cent), sugarbeets (-26 per cent), rice (-18 per cent), wheat (-12 per cent) and corn (-10 per cent). The production of these crops decreased not only because of diminishing supplies of water but also to lower prices resulting from sizable global stocks of food and feed grains. The reduction in sorghum was probably most directly related to the drought since sorghum is frequently grown as a second crop. The reduction in rice was also related to the drought since it, a high water-demand crop, was replaced by oats, a low water-demand crop. Acreage in some crops such as cotton was increased 19 per cent over the previous year because of both favourable market conditions and its salt tolerance, which made it eligible for the postponed leaching technique.

FUTURE PROBLEMS CREATED DURING THE DROUGHT

Several problems may result from obtaining the needed water supplies for 1976-1977. As mentioned above, farmers relied on ground-water pumping in order to make up some of their surface-water deficiencies. A heavy reliance on ground-water pumping, however, is accompanied by potential adverse effects such as well collapse, ground subsidence, and the possibility of wells going dry.

The extensive use of ground-water sources in a drought year may affect future recharge rates. In 1976, with less applied surface water, the recharge of deep ground-water reservoirs was reduced and its depletion continued unbalanced. The quantity of ground-water orderdraft in 1976 was estimated to have been 4.9 million acre-feet compared to about 2.1 million acre-feet in 1975. Over 80 per cent of this overdraft occurred in the Central Valley with the worst impact in the southern San Joaquin Valley. In 1977, because of a continued reduction in surface-water supply, pumping from ground-water storage reservoirs reached as much as 10 million acre-feet out of the state-wide total of 18.5 million acre-feet (California Department of Water Resources, 1977). Overdraft and ground subsidence lead to a collapse of ground formation which reduces the water storage capacity. In view of the possibility of future drought periods, the replenishment of ground-water basins is a problem requiring consideration in the near future.

Another problem with reduced water applications and rates is that there is less soil moisture carry-over into the next growing season. In addition, minimal water appliction together with the use of a lower quality of water for irrigation may cause more severe soil salinity problems. For a permanent irrigated crop, salt must be removed from the soil at the same rate it is introduced by irrigation water, or a steadily increasing salt concentration in the soil water will cause a progressive reduction in crop yields. The relationship between reduced water application, soil salinity, and ground water as they apply to the total salt balance picture is a critical question that needs to be considered.

CONSERVATION OF WATER AND ENERGY IN THE AGRICULTURE SECTOR

The drought conditions of 1976-1977 have shown both the necessity and ability to conserve water in

Table 1. Plantings of selected crops in California, 1975-1977

Crop	*1975*[a]	*1976*[b]	*1977*[c] *(estimated)*	*1976-1977 estimated difference*
		(1 000 acres)		*(percentage)*
Field crops				
Alfalfa	1 650.0	1 630.0	1 670	+ 2.0
Barley	1 220.0	1 200.0	1 150	- 4.0
Beans	154.0	179.0	176	- 2.0
Corn	420.0	480 0	430	- 10.0
Cotton	900.0	1 120.0	1 350	+ 19.0
Oats	365.0	385.0	400	+ 4.0
Potatoes	15.0	16.0	16	+ 0.6
Rice	530.0	421.0	345	- 18.0
Sorghum	230.0	235.0	150	- 37.0
Sugarbeet	333.0	318.0	235	- 26.0
Wheat (excl. Durum)	1 060.0	1 000.0	885	- 12.0
Wheat (Durum)	15.0	90.0	30	- 67.0
Fruit/Nuts[d] (excl. grapes)	1 335.0	1 335.0	1 335	...
Grapes	647.0	631.0	647	...
Vegetables (excl. tomatoes)	616.1	555.7	620	+ 12.0
Tomatoes	305.6	267.7	280	+ 5.0

Notes: *a* *Principal Crop and Livestock Commodities-- 1975,* California Crop and Livestock Reporting Services, United States Department of Agriculture (USDA), June 1976.

b *Principal Crop and Livestock Commodities-- 1976,* California Crop and Livestock Reporting Service, USDA, June 1977.

c *Crop Intentions Report,* California Crop and Livestock Reporting Service, USDA, June 1977.

d *California Fruit and Nut Statistics (1975-76),* California Crop and Livestock Reporting Service, USDA, February 1977.

agriculture, as well as in other sectors of our society. Because of the use of energy for water delivery and use, water conservation can mean energy conservation as well, though this is dependent on the irrigation method used. In a normal rainfall year, the electricity savings associated with water conservation could be as much as 25 per cent (Energy Research and Development Administration, 1976).

The requisites for implementation proceed on many levels. Some measures, such as cutback irrigation, require only a change of practice on the part of the farmer. Some strategies begin to involve other sectors through the purchase and installation of equipment or the change of labour schedules. At the widest extreme, a change of governmental policy may be required. While may conservation strategies are implemented ultimately on the farm, the policies and practices of broader levels of organization (e.g. water districts or the federal Governments) can affect the facilitation of the necessary changes.

Some measures, such as minimal leaching, are explicitly short-term in application because of their cumulative adverse effects. Other measures can be incorporated into a continuing conservation effect because increasing water demands will affect water price and availability. Generally, the more elaborate the physical set-up, the longer the lead time needed to implement the measure.

Table 2 gives several general approaches to agricultural water and energy conservation which cover a variety of individual strategies. The dimensions in which these approaches vary are not only the level of implementation including lead time, technological

Table 2. Strategies of conservation in agricultural irrigation

Strategy	*Type of implementation*	*Electricity savings*	*Implementation criteria*
		MAINTAINING AND AUGMENTING SURFACE WATER SUPPLY	
Phreatophytic control	now	through water savings	Ecological alteration
Ditch and canal lining	now or a few months	10 per cent water savings	Loss of percolation
Use of reclaimed water	4 to 8 years	5 to 10 per cent water saving energy cost in processing	Dependent on basin hydrology and topography
		POWER USE EFFICIENCY	
Well maintenance	now	some	Best for new wells, also reactivated wells
Well efficiency	4 to 7 years	2 to 10 per cent	
Pump maintenance	now	15 to 35 per cent, probably 15 per cent	Especially for pumps older than 5 years
Pump and motor efficiencies	5 years	2 to 5 per cent	Big pumps are more efficient
		IRRIGATION EFFICIENCY	
Cutback irrigation	now	through water savings	Greatly improves water use efficiency of surface irrigation and leaching uniformity
Tailwater re-use	now	through water savings	Benefit depends on basin hydrology, water costs and topography
Sprinkler systems	now	through water savings	Benefit depends on well depth; can increase plant diseases; inefficient in desert areas
Drip systems	now	through water savings	Most profitable for high-value crops
Gated pipe	now	through water savings	Prevents erosion on steep slopes; increases areal distribution from single water source
Irrigation management	now	25 per cent	Limited trained personnel, tailored to site, increased yield offsets fee

development and cost, but also geographic factors such as climate, soil and marketing of crops. A discussion of those strategies that are relevant to water and energy conservation in California and which can be implemented in the near term follows.

Maintaining and augmenting surface-water supply

(a) *Reducing and percolation losses.* By lining major canals, ditches, and drains and substituting closed pipe, where practical, for open laterals, farm head ditches and drains, deep percolation of water supplies can be decreased, except that required for leaching accumulated salts from the salt profile. The elimination of phreatophytes (water-loving plants) from irrigation ditches and canals would also reduce water consumption by as much as 10 per cent. Each of these methods subsequently would save electricity through the savings of water. However, the methods are not without problems. For example, while elimination of phreatophytes would slightly increase ground-water recharge, the use of herbicides and the loss of wildlife habitats may counter the water savings. For another example, percolation is necessary to maintain both ground-water supplies and the underground storage capacity, but may be so costly, where pumping energy is a critical factor that canal lining may be more desirable.

Similar problems are involved in the building of storage reservoirs. Reservoirs suffer water loss from

ground and surface, though they can be lined and covered. Additionally, if they are built in proximity to the area where the water will be used, good land may be taken out of production. The great advantage of reservoirs is that they allow greater flexibility in scheduling irrigation.

Using reclaimed waste water

Substituting water reclaimed from industrial and municipal use for fresh water in agriculture is possible because a lower water quality is required for those crops not directly consumed by people. Given that treated water is available for irrigation, the savings in terms of energy for ground-water pumping has been estimated to be potentially 5 to 10 per cent (California Department of Water Resources, 1976a). Whether energy can be saved depends on the amount of treatment required for various agricultural purposes and the elevation change to delivery point. Another complication in evaluating the impact of waste-water irrigation is that transferring water from one hydrologic basin to another may lower the water table of the supplying area.

Increasing power use efficiencies

(A) *Well efficiency and maintenance.* The amount of energy necessary to lift a given volume of water depends not only on the well depth, but also on the well efficiency. It is important that the well be drilled properly in the first place and that it be maintained for maximum efficiency. A programme to upgrade and standardize the drilling of new wells could be implemented in the near term.

(b) *Pump efficiency and maintenance.* Many pumps have lower efficiencies because they are out of tune. Efficiency tends to be fairly high for the first five years of operations, but drops sharply after that (Nebraska Center for Continuing Education, 1977). A tune-up will improve the efficiency and should last three years, which is about the time necessary for the energy savings to balance the costs (Roberts, 1977). A more thorough investigation shows that the cross-over point between costs and benefits varies with the units of analysis. In monetary terms, pumps should be rebuilt after about five years, depending on use; in energy terms, it should be done after two years.

The weighted average pump efficiency in California is 55 per cent. This average is weighted for pump capacity since larger pumps are generally more efficient. The pump efficiency could easily be improved to 65 to 70 per cent, which would yield a 15 per cent energy savings (Roberts, 1977).

Increased irrigation efficiencies

(a) *Reducing water application.* The greatest potential for energy and water conservation in agriculture seems to be in the area of increasing irrigation efficiencies. The relationship between the amount of water applied and crop yield is a direct one up to the limit of the maximum transpiration. The more water applied, the greater the yield is until the crop is over-irrigated and root damage results. On the other hand, reducing water application below the maximum plant use level may cause a drop in yield tonnage. In the case of orchard and vine crops, such reduction is not altogether unfavourable because it may bring about improvement in flavour and shipping characteristics. Perhaps with this kind of tradeoff in mind, a programme of soil water depletion can be co-ordinated with crop growth stages to minimize adverse effects of plant stress; there are, of course, limits to this strategy. When leaching is cut, the soil salinity rises and interferes with crop growth especially during the period of germination. This problem is more severe in areas where the soil has a high salt content. Depletion of soil moisture is possible only with deep-rooting crops that have a large enough root area to draw the water needed for growth.

One way to maintain soil moisture and to minimize risk of over-depletion is to apply mulch to the surface. Reduction of water loss (ranging from 16 to 49 per cent) has been reported (Davies, 1975). There are minimum and maximum points beyond which the amount of mulch does not affect moisture retention. The tradeoff between cost and energy savings is unknown, but implementation is readily accomplished.

(b) *Tailwater re-use.* In a gravity system without recycling, only part of the water is actually used by the plant. By installing pumps to collect runoff and then pumping the excess back to the field, the water can be reused. In fact, such re-use systems are already employed extensively in the San Joaquin Valley. The energy efficiency of a return flow system depends on size and slope of the field and the depth from which water is pumped. In terms of pumping energy and well depth, tailwater re-use becomes advantageous for wells deeper than 25 feet. If the water table is not extremely deep or if water is not transported over mountains (as for San Diego and Los Angeles Hydrologic Basins), the additional energy to pump tailwater to the top of the field increases the total energy requirement for irrigation on a basin-wide average.

A tailwater re-use system with proper use can compare favourably in efficiency with sprinkler system (California Department of Water Resources, 1976b). Irrigation efficiency is improved from 65 per cent for regular furrow irrigation to 81 per cent by reusing one quarter to one third of the water. Additionally, plant diseases which are spread through runoff can be controlled.

In many districts, it is not necessary for the farmers to re-use tailwater to achieve a high district efficiency. Often the irrigation district collects the runoff and sells it downslope to other users.

(c) *Sprinkler, drip and gated-pipe irrigation.* Sprinklers increase water usage efficiency by applying water more uniformly and more closely to needed amounts. However, pressurizing the water to disperse it requires pumping energy. If water has to be pumped from deeper than 300 feet, it is more economical to use water, so that the smaller energy cost of sprinkler pressure makes the total investment cost-effective. Energy savings can be extended by using lower pressure nozzles that could provide as much as 10 per cent savings (though currently they are not widely used). Problems to consider in using sprinklers are that water from sprinklers can increase plant disease incidence, and cause higher exploration rates.

In drip irrigation, water trickles from an emitter in a pipe. The water must be filtred under slight pressure to prevent the emitters from becoming clogged. Drip irrigation requires a lower pressure than sprinklers, but its feasibility is limited to widely spaced crops. The economic advantage to the farmer is greatest for high-value crops such as trees and vines or where water is expensive, because the installation and labour costs for the system are great.

Gated pipe allows greater area distribution of water from a single source. It can be used on steep slopes where surface methods would cause erosion. Since water in the pipe needs little additional pressure, gated-pipe irrigation offers a much greater energy savings than sprinkler and drip systems. With automated control, as much as 50 per cent energy savings can be achieved (Nebraska Water Resources Research Institute, 1973).

All the systems described here have the advantage of providing more uniform application of water and more control for varying conditions in a field. These and other advantages peculiar to the system will have to be weighed against the fact that conversion to any of these systems takes time and money to design, order, deliver, install and adjust before any savings will be realized.

(d) *Irrigation management.* Irrigation management is probably the most direct approach to water and energy conservation in agriculture. An example of a management technique is to irrigate with the proper amounts of water by monitoring soil moisture levels so that the quantity of water that has to be pumped during the growing season is reduced. There are three distinct elements to irrigation management: measurement, scheduling and operation. The elements yield information, such as the amount of water to apply, by determining the amount of water that is available to the crop and the water needs of the crop.

Water flow rate is also determined in an irrigation management programme, and this is used in measuring pump and well efficiencies. Water use can be reduced by eliminating the error in the amount of application, which can be off by 20 to 40 per cent (Nebraska Center for Continuing Education, 1977). This requires the installation of a meter and the effort to use it.

Farmers are unfamiliar with irrigation management techniques and require some training and experience to use them. Services are available to supply the information needed to set up an irrigation programme, such as field measurement of soil moisture and computer analysis of meteorological data. But because there is a shortage of trained personnel in irrigation management, the expansion of this practice will be limited for the next few years. A solution to this limitation would be to disseminate the basics of measurement and scheduling to farmers so that they could undertake their own irrigation management.

Irrigation management does require an investment in labour and often capital as well. However, the potential savings are substantial enough to make it worth consideration. A savings of 25 per cent of the energy used in pumping can be realized while maintaining yields.

INSTITUTIONAL FACTORS AFFECTING CONSERVATION

While conservation practices occur on farms and in water districts, their implementation relies on constitutional structures and policies. Among these institutional settings that affect water use are: water rights and quality laws, water pricing structure, and information services.

Water rights in California are based on actual use. This is commonly interpreted to mean "use it or lose it", and many farmers maintain wasteful practices in the belief that establishing use will serve as a hedge against future water needs. Despite the law's requirement that use must be beneficial and reasonable, and that the user stands to lose the excessive amount if he has been wasteful, there is little enforcement by the state to substantiate the law. Most investigations of wasteful practices are being done on the basis of complaints.

While to some degree water quality standards limit the availability of water and affect the cost, generally they serve to promote minimal leaching by keeping the salt levels down in both the inflow and outflow of water through the soil (Willey, 1977).

The availability of water is affected in the physical sense by the current capacity and delivery time requirement of the water resource system. In the long-term, however, it is the agencies involved with water resources that affect availability, because they can plan development to increase supply or to use available supplies more efficiently. One of the major tools that can be used to implement efficient use is water pricing. Currently, cost per acre-foot for surface water is one half to one tenth the cost of pumping ground water, at the rates

charged by the water agencies, since these surface-water rates are subsidized. In some water districts the rates are structured so that the more water used, the lower the cost per acre-foot. In others there is one initial charge for using water up to a certain amount. This latter pricing practice encourages farmers to use that full amount irrespective of actual need because they have paid for it. When excessive surface water is applied, the percolating water recharges the aquifer. The raised water table makes the cost of pumping from private wells less than in normal conditions. The result is essentially that surface water is made accessible through these wells, thought their operators do not pay for water delivery (Lyford, 1978).

Raising the price for use of surface water above a minimal amount has been suggested as an incentive for water conservation. No longer subsidizing water prices for agriculture would allow other users such as industry and power generation to compete economically for use of water resources and force farmers to use water more efficiently. While it has been suggested earlier in this paper that there is water wastage that can be eliminated, effective pricing to discourage waste must first define what constitutes minimum water use, and what is efficient use once wastage has been eliminated.

The determination of minimum water use must consider the following factors.

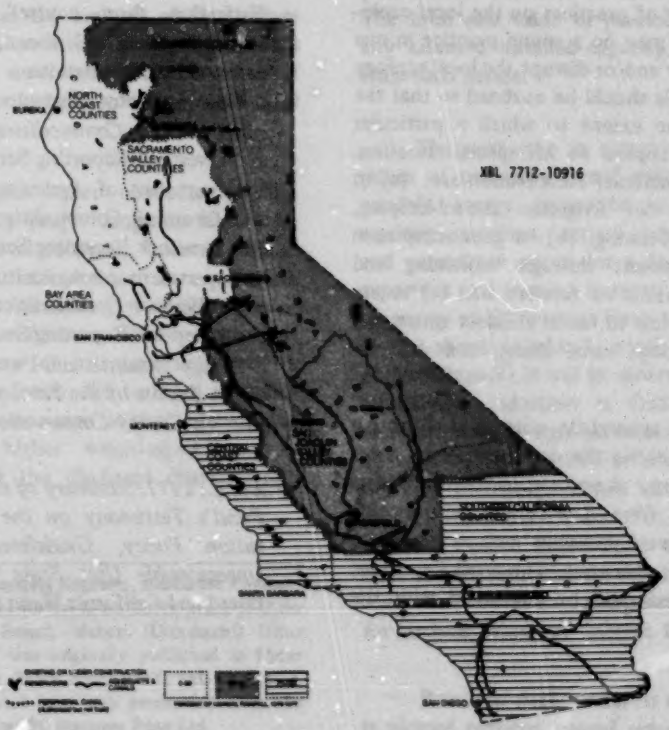
(a) The amount of water needed for the quality and quantity of crop yield that the farmer must have for economic survival.

(b) The quantity of crop yield that can economically absorb established costs such as pest control. These costs remain relatively constant regardless of yields, so that maximum yield makes the most efficient use of them.

(c) Availability of a greatly expanded and improved data collection for crop, soil type, weather, topography, without which a local minimum cannot be established.

(d) The price of water above any minimum should not become so much greater than the cost of pumping ground water as to encourage ground-water use and aggreviate ground-water depletion. In sum, both ground- and surface-water availability must be incorporated in water conservation policy. These factors need to be balanced with the farmer's profit margin.

Making information about conservation practices available to the farmer will facilitate their implementation. Such services currently are in operation on various levels. There are private consulting firms which can advise the farmer on all phases of field operations. At the state level, the agricultural extension in each county offers information and help to improve farming practices. This service requires that the farmer request such information or help. Under the U.S. Bureau of Reclamation is the Irrigation Management Service which involves both individual farmers and water districts. These services act to improve the farmer's situation by relating activities in the agricultural sector to those of other sectors.



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The planning agencies should be concerned with issues related to the infrastructure of water resource use. In this concern, they need broadly based and comprehensive information in order to have a sound basis for policy information. Good information, unfortunately, is not available in all areas.

PROSPECTS FOR CONSERVATION

In the agricultural sector, water conservation and energy conservation have a complex interrelationship. While energy may be conserved independently of water, as in pump and well efficiencies, for the most part energy is directly or invesely proportional to water use. In the abstract, it is possible to budget water and energy use, even with regional variations of soil, topography, and water availability. In actuality, other factors such as labour, time, and capital outlay play a major role in the farmer's estimation of the feasibility and profitability of implementing conservation strategies. The decisions of individual farmers about water and energy conservation are made within the institutional structure of water district operations, water agency policy, state and federal water quality standards, and water rights laws. These structures affect the farmer's evaluation of conservation in terms of what is feasible and what are the benefits and costs involved.

The treatment of conservation in this paper leans toward strategies that can be implemented in the near term. While conservation is clearly both necessary and possible, there needs to be a better understanding of the impact of practices on the local ecological conditions. What may be a sound practice in one area, may waste energy and/or disrupt the local ecology in another area. Criteria should be outlined so that the farmer understands the extent to which a particular conservation practice applies to his special situation. Actions which would facilitate conservation are: (a) to establish programmes for irrigation record-keeping, pump-testing, and well-testing; (b) to gain acceptance for irrigation management through explaining and demonstrating the benefits to farmers; and (c) to encourage irrigation districts to foster efficient water use, maintain supplies through canal lining, and generate power where possible.

Energy plays a synergistic role in Californian agriculture, making effective the combination of water land, labour, machinery, chemicals, and other inputs to produce food and fibre. The future requirements and limitations on natural resources such as water and energy are uncertain at this time. The most important of all resource questions will be concerned with the amount of available water and energy, the efficiency and cost of their use and allocation among agricultural as well as competing users. Energy prices will probably continue to rise in the future and the potential for economic payoff from conservation and end-use efficiency will persist.

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SELECTING INSTALLED CAPACITY FOR A RUN-OF-RIVER PLANT

*D.P. Sharma, G.L. Verma, A.K. Bahadur**

Where energy demands are increasing and resources limited, the traditional notion of developing a hydro site to yield optimum financial returns should be modified so as to obtain optimum returns in power and energy as well as money. The authors show the general principles behind this argument, and illustrate them with reference to a particular project.

The cost of a project and likely returns in terms of power, energy and money are based on a set of independent as well as interrelated multi-variables. Any exercise in optimization calls for mathematical modelling or graphical analysis. We have chosen the graphical approach.

A run-of-river scheme normally comprises of the following components:

(a) Diversion works comprising of a small diversion dam or barrage and intakes;

(b) A water conduction system comprising of power tunnels and penstocks; and,

(c) A powerhouse complex.

The size of diversion dam or barrage, is decided on the basis of engineering, geological, ecological or social considerations. The pondage is minimal—generally just enough to cater to the diurnal peaking requirements. Construction of a small diversion structure and the resulting reservoir reduces the amount of firm power that can be generated at such sites during the months of lean discharges, but a small variation in the reservoir water level ensures a practically constant gross head on the turbines.

While designing the water conductor system in a run-of-river scheme, proper emphasis should be given to aspects of over-all economy, because judicial selection of a tunnel diameter can lead to a reduction in head losses, thereby increasing the efficiency of utilization. Reduction in friction losses provides for higher generation by way of increased net head; in addition, because of low losses, the turbines are called on to operate in the peak range of their efficiencies, thereby resulting in higher weighted efficiencies. However, depending on the discharge characteristics of the river and the length of the tunnel, there is a limit to the reduction in friction losses which can be economically justified.

Usually the project reports in India are formulated on the basis of 90-per cent availability discharge figures. Depending on the difference between 90 per cent and average discharge availability figures, either of the two can be chosen for consideration.

There are three steps which determine the selection of installed capacity, and the other elments of the project—such as tunnel size and capacity of intake works. From the flow duration curve and known gross head, a set of power duration curves can be drawn (see figure 2). This has to be done after allowing for some assumed friction losses in the water conductor system. Depending on the amount of gross head available at a particular site, these curves can be plotted for friction losses varying in steps of 2.5 or 10 m. The area under each such curve gives the total energy potential of the river at the site under consideration. The total sale value of possible energy generation, at any assumed installed capacity, can also be calculated from such curves.

The next step in the exercise is to tabulate the values of necessary tunnel diameter, design discharge, possible energy generation, cost of project, annual working expenses, annual returns (surplus revenue) and percentage return for a suitable range of installed capacities and friction losses at the prevalent sale value of energy at the busbar. From this information (similar to that shown in table 1, which applies to Maneri Bhali project Stage-II), it will be observed that, at any installed capacity, a reduction in friction losses by way of increased tunnel size is economically justifiable only up to a specific limit. For any installed capacity, the value of percentage return initially increases with the decrease in friction losses but, after reaching a peak, falls off rapidly. This will be all the more apparent if a set of surves showing the relationship between installed capacities, capital cost and percentage return are plotted for various values of friction losses (figures 3 and 4).

Based on data similar to those in table 1, a curve is plotted between annual return (surplus and installed

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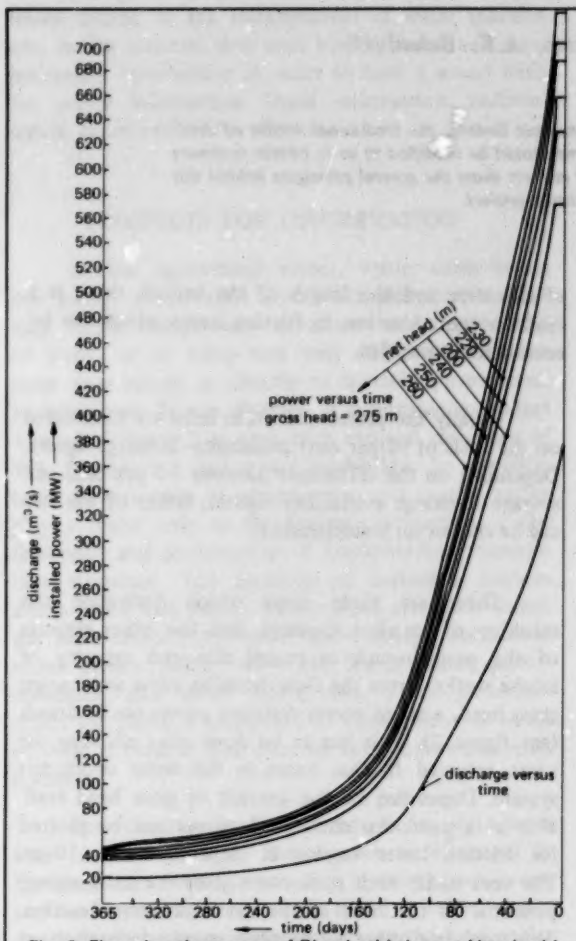

Fig. 2. Flow duration curve of Bhagirathi river at Uttarkashi. The resulting power duration curves have been plotted for friction losses ranging from 15.0 m to 55.0 m.

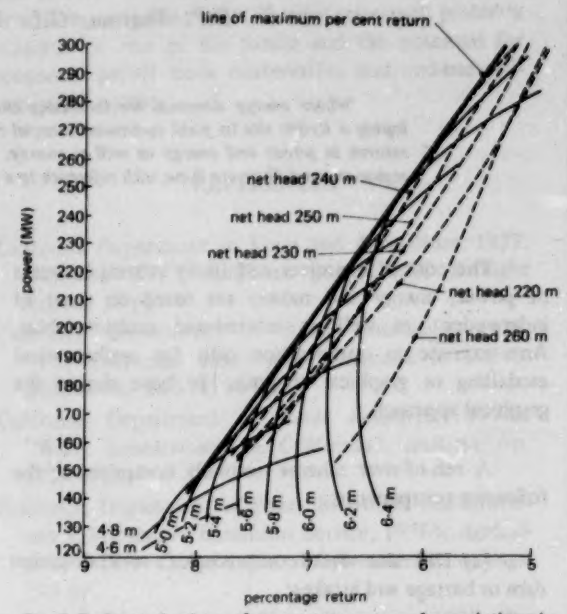

Fig. 3. Estimated values of percentage return, for variations in tunnel sizes from 4.6 m to 6.4 m and net head from 220 m to 260 m.

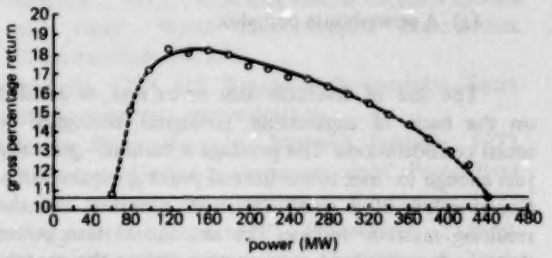

Fig. 4. Maximum possible percentage return that can be obtained for any scale of development with minimum investments.

From figure 5, which shows the relationship between annual return (surplus) and installed capacities, with the water conductor system designed to yield the maximum possible percentage return, it is apparent that the maximum surplus revenue is obtained with an installed capacity around 250 MW.

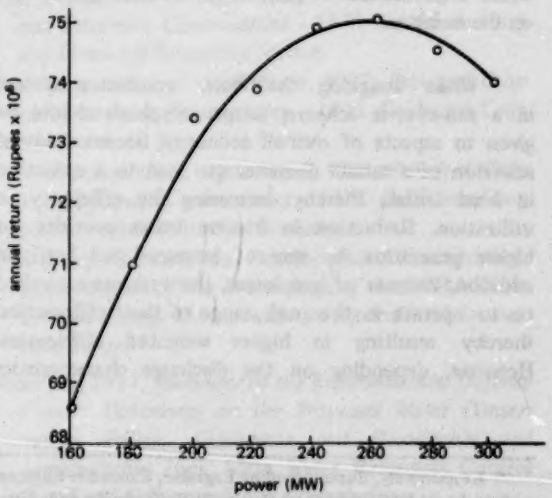

Fig. 5. Relationship between annual return (surplus revenue) and scale of development in MW, with the water conductor system designed to yield maximum efficiency in economical terms.

The Board of Consultants for Maneri Bhali project, Stage-II, in its meeting held in December 1978, while recommending the adoption of this approach, had recommended that the size of tunnel should not be greater than 7 m (excavated diameter). This was because of the problems that were likely to be encountered while tunnelling through the zone of Srinager thrust, which crosses the path of tunnel alignment. The finished size of the tunnel, suitable for generation of 250 MW is just within the limit recommended by the Board.

The details of the project, as originally proposed and those now being recommended for adoption are as listed in table 2.

Table 1. Costs and return for various parameters at Maneri Bhali (gross head = 275 m)

Friction losses (m)	Net head (m)	Design discharge (m^3/sec)	Necessary tunnel diameter (m)	Capital cost of project (Rs X 10^6)	Annual cost (Rs X 10^6)	Possible unit generation (kWh X 10^6)	Annual return (surplus) unit value of energy (18 paise/kWh)	Percentage return
				160 MW				
55	220	84	4.9	844.8	89.5	866	63.2	7.48
45	230	81	5.0	857.2	90.9	880	64.4	7.51
35	240	77	5.2	870.3	92.2	897	66.0	7.58
25	250	74	5.5	892.7	94.6	909	65.7	7.36
15	260	72	6.1	950.5	100.7	920	61.6	6.48
				180 MW				
55	220	95	5.15	921.7	97.7	921	64.7	7.01
45	230	91	5.3	932.9	98.9	936	66.2	7.09
35	240	87	5.4	939.1	99.5	958	69.4	7.39
25	250	84	5.7	965.0	102.2	969	68.6	7.10
15	260	80	6.3	1 020.0	108.1	978	64.4	6.31
				200 MW				
55	220	106	5.4	1 000.9	106.1	973	65.5	6.54
45	230	101	5.5	1 006.0	106.7	989	67.7	6.73
35	240	97	5.7	1 021.6	108.3	1 013	70.3	6.88
25	250	93	6.0	1 047.1	110.9	1 026	70.0	6.68
15	260	89	6.6	1 100.0	116.8	1 038	66.5	6.04
				220 MW				
55	220	116	5.6	1 074.8	113.9	1 024	66.7	6.20
45	230	111	5.7	1 079.1	114.3	1 041	69.3	6.42
35	240	107	5.9	1 094.1	116.0	1 068	72.3	6.60
25	250	102	6.2	1 120.0	118.7	1 079	71.6	6.39
15	260	98	6.8	1 176.0	124.5	1 104	70.1	5.96
				240 MW				
55	220	127	5.8	1 147.8	121.6	1 069	67.0	5.83
45	230	121	5.9	1 151.6	122.0	1 090	70.2	6.09
35	240	116	6.1	1 168.8	123.9	1 115	72.7	6.20
25	250	112	6.4	1 193.0	126.4	1 129	72.7	6.09
15	260	108	7.0	1 247.4	132.1	1 153	71.2	5.71
				260 MW				
55	220	137	6.0	1 220.8	129.4	1 114	67.1	5.49
45	230	131	6.1	1 227.2	130.1	1 134	69.9	5.69
35	240	126	6.3	1 233.9	131.3	1 164	74.0	5.97
25	250	121	6.6	1 265.2	134.0	1 177	73.5	5.81
15	260	116	7.2	1 320.7	139.9	1 200	71.2	5.43
				280 MW				
55	220	148	6.2	1 294.9	137.3	1 156	66.8	5.15
45	230	141	6.3	1 297.8	137.6	1 176	69.8	5.37
35	240	136	6.5	1 313.2	139.2	1 209	74.0	5.63
25	250	130	6.8	1 337.8	141.7	1 223	73.9	5.52
15	260	125	7.4	1 393.2	147.6	1 246	72.1	5.17
				300 MW				
55	220	159	6.3	1 357.8	143.9	1 193	66.5	4.89
45	230	151	6.45	1 370.7	145.2	1 219	69.8	5.08
35	240	146	6.7	1 388.9	147.2	1 246	72.4	5.21
25	250	140	7.0	1 409.7	149.3	1 262	73.3	5.20
15	260	134	7.6	1 465.7	155.3	1 288	71.9	4.90

Note: Rs refers to rupees, the national currency; 100 paise make one rupee.

Table 2. Original and modified details of Maneri Bhali project; Stage-II

	Original (156 MW)	Modified (250 MW)
Installed capacity (MW)	156	250
Design discharge (m^3/sec)	75.0	120
Tunnel diameter (m)	4.8; circular	6.1; Horseshoe section
Capital cost of project (Rs X 10^6 approx)	826.3	1 200.00
Possible energy generation (kWh X 10^6)		
(a) At 90 per cent discharge availability	840	1 150
(b) At average discharge availability	1 060	1 475
Annual return (surplus) (Rs X 10^6)		
(a) At 90 per cent discharge availability	60.5	75.0
(b) At average discharge availability	99.4	133.0
Percentage return:		
(a) At 90 per cent discharge availability	7.32	6.25
(b) At average discharge availability	12.02	11.08
Cost per unit (paise/kWh)		
(a) At 90 per cent discharge availability	10.64	11.28
(b) At average discharge availability	8.43	8.8

Note: Same as Table 1.

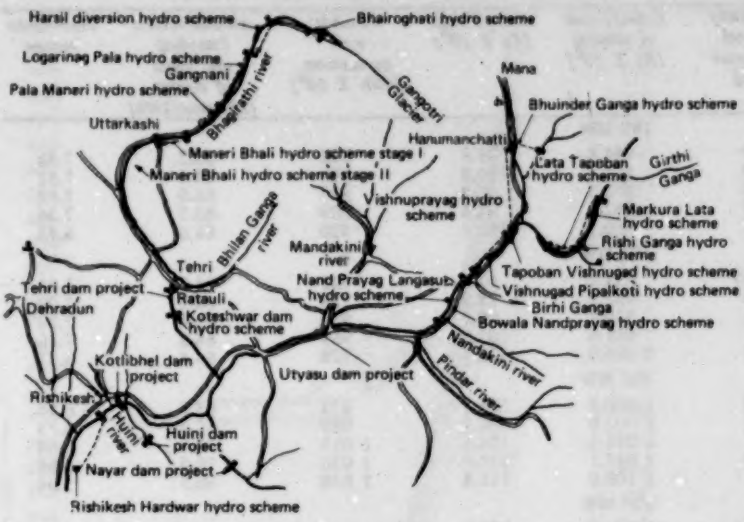

Fig. 1. Proposed major hydro stations to be constructed in Bhagirathi and Alaknanda valleys. In addition to those marked in the map, there will be many mini-hydro stations with capacities less than 500 kW, for supplying power to local towns and communities.

capacity (similar to that in figure 5). For a selected value of net head or friction loss in a water conductor system, it will be observed that the annual return (surplus) also rises initially with the increase in installed capacity and, after reaching a peak, starts falling. This is because, beyond the peak, the increment in annual cost corresponding to the increase in installed capacity is more than the annual revenue that can be derived by way of increase in installed capacity. This means that addition capacity beyond the value represented by the peak would be uneconomical, and would lead to reduction in total surplus revenue.

Thus from the analysis of data tabulated in table 1 and the pattern of curves in figures 3, 4 and 5, the optimum plant capacity yielding optimum returns in terms of energy power and surplus revenue can be decided.

Example: Maneri Bhali, second stage

These principles were adopted for modifying the originally proposed installed capacity of the Maneri Bhali project, Stage-II. The project envisages utilization of the hydroelectric potential of the Bhagirathi River, between the tailrace of the Uttarkashi power station and the headwaters of the Tehri Dam. The gross head available at site is of the order of 275.0 m and the flow pattern in the river, on a 90-per cent availability basis, is as shown in figure 2. The original project report recommended construction of a 156 MW station, with

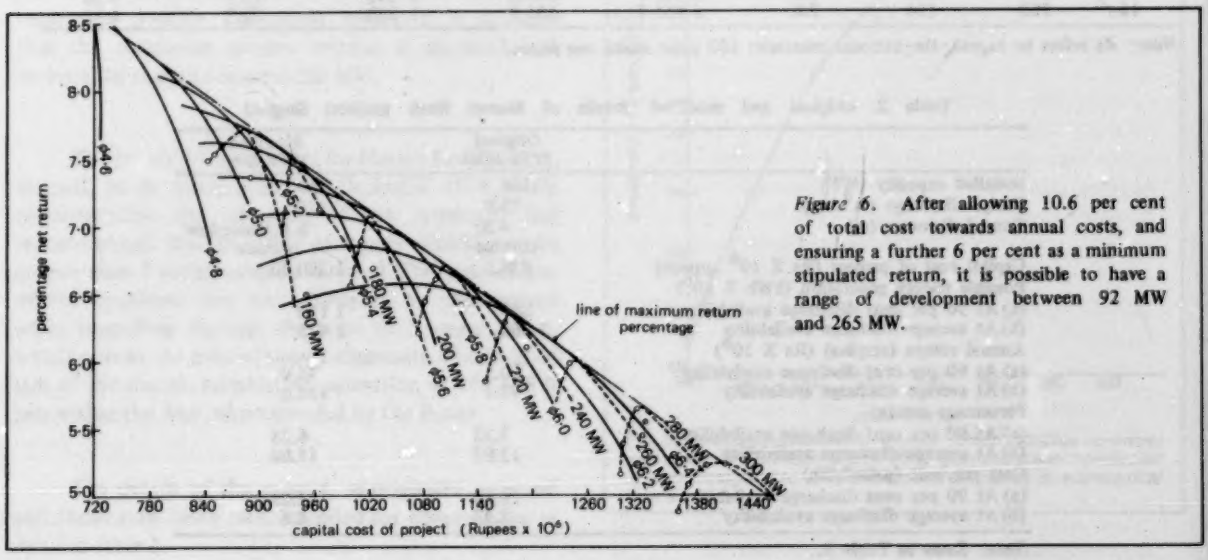

Figure 6. After allowing 10.6 per cent of total cost towards annual costs, and ensuring a further 6 per cent as a minimum stipulated return, it is possible to have a range of development between 92 MW and 265 MW.

associated works consisting of a barrage at Uttarkashi, an intake designed for 75.0 m^3/sec discharge, and a 4.8 m-diameter, 15.4 km-long power tunnel. The project was estimated to cost around Rs 826.3 million ($US 105 million).

The review of project report was undertaken on the basis of principles outlined above. The cost-benefit analysis for the hydroelectric development of the site was carried out for a scale of development ranging from 100 to 300 MW. The height of the diversion structure, i.e., the barrage, has been limited and kept as originally proposed in order to avoid submerging the town of Uttarkashi.

The size of the water conductor system determines the net head that can be made available on the turbines. For drawing the power duration curves in figure 2, five different water conductor systems were posited—the friction losses in them varying from 15.0 to 55.0 m. This is effect meant that the net head on the turbines was taken to vary from 220 to 260 m.

From the details given in table 1, and curves plotted in figures 3 and 4, it was noticed that for any scale of development, the values of percentage return rose with the increase in net head from 220 to 240 m, and after attaining a peak for a value of net head between 240 m and 250 m, had a tendency to fall. This clearly indicated that any attempt to reduce the friction losses to a value lower than that represented by the bold line in figure 3 would prove uneconomical. Studies revealed that the scale of development could be anywhere between 92 and 265 MW (figure 6) to ensure a net percentage return of 6 per cent on invested capital. Maximum gross percentage return is gained with an installed capacity around 120 MW.

However, since the intention is to develop the site to an optimum extent, the returns in terms of power, energy and money, all have to be taken into account.

DECLINING BLOCK RATES CAN ENCOURAGE WATER CONSERVATION

Lloyd Sawchuk[1]

Declining block-rate pricing policies are increasingly criticized as encouraging waste and promoting inefficient water management. These criticisms are invalid. Cost-based declining rates are economically sound and actually encourage water conservation for most utilities with a diversified customer mix.

The political and social environment facing a water utility planner is complex. Among the often contradictory opinions expressed by the public is the persistent call for a rate structure that will promote water conservation. The traditional declining block rate structure, which is a reflection of the costs of providing service, is rejected on the grounds that it encourages waste and inefficiently uses a scarce resource. The single-unit or inclining block rate structures for water are increasingly promoted as ideal pricing strategies that will encourage water conservation.

Price elasticity and water conservation

Price elasticity (the relationship between the price of a good and the quantity of the good a consumer will demand) is the watchword. Everyone knows that if the price of water increases, customers will use less water. Therefore, it is argued, eliminating the price discount to large users will encourage them to use less water. This may be true. However, the total water consumption of the utility may increase. At first glance this statement appears to be in direct conflict with the concept of price elasticity, but a closer look reveals the opposite.

On the average, assuming all else remains equal, only homogeneous customer groups tend to respond

The total revenue needs of most water utilities are determined separately and apart from the water-consuming marketplace. In the long run the revenue needs of a publicly owned utility must equal cash requirements. The timing of cash flow can be influenced by the use of debt financing or, in the case of privately owned utilities, through the combination of additional capital investments and the use of debt. Nonetheless, that a utility's cash inflow must ultimately meet its cash outflow is an inescapable fact.

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1 Assistant Treasurer, East Bay Municipal Utility District, Oakland, California 94623, United States. This article was originally published in *Journal - AWWA* (ISSN 0003-150X; vol. 73, No. 1, January 1981), and is reprinted here with permission from the publishers. Copyright 1981 by the American Water Works Association.

to changes in the price of a good by adjusting their consumption of the good in a uniform manner. A multitude of studies have been made and published regarding price elasticity. While these studies have never arrived at a universal value for the price elasticity of water, they unanimously conclude that residential and commercial-industrial customers are not a single homogeneous group. Water to a residential customer is a consumer good. Water to a commercial-industrial customer is a producer good. Water use patterns of both groups are distinct. This distinction in use patterns has been documented in studies merging the science of economics and probability theory.

A price elasticity coefficient of –0.3 for water means that a 1 per cent increase in the unit price of water to a customer will result in an expected 0.3 per cent decrease in the total quantity of water the customer will consume. Conversely, a 1 per cent decrease in the unit price of water would result in an expected 0.3 per cent increase in water consumption.

The demand for water is typically described as "price inelastic". This means that the percentage change in a customer's consumption as a direct result of a given change in price will be expected to be smaller than the percentage change in price. A price elasticity coefficient is typically a negative number. Decreases in the price of a commodity are normally expected to result in increases in consumption of that commodity as long as other factors remain unchanged.

The classic, most widely referenced research on price elasticity for water is the Howe and Linaweaver study, which estimates the elasticity coefficient of residential customers to be –0.225,[2] and the Hanke and Davis study for commercial and industrial customers, which estimated the price elasticity of these customers at –0.10.[3] The price elasticity coefficient for residential customers in the East Bay Municipal Utility District service area was estimated to be in the range of –0.15 to –0.3 in a recent comprehensive study.[4]

Application of price elasticity theory

To illustrate the effect of having two classes of customers with differing elasticity coefficients, assume the total revenue needs of a water utility are $US 10 million. All of this revenue is currently recovered through a volume charge under a declining block rate structure at $0.50 per unit for 0 to 40 units and at $0.40 per unit for more than 40 units. Water consumption under this rate structure is listed in table 1.

Table 1. Water consumption rates and annual revenues for a utility using a declining rate structure

Rates of Consumption	*Price elasticity coefficient*	*Water sales (units)*	*Annual revenues ($US)*
0 to 40 units at $US0.50 per unit			
Residential	-0.225	8 000 000	4 000 000
Commercial and industrial	-0.10	2 000 000	1 000 000
Subtotal		10 000 000	5 000 000
More than 40 units at $US0.40 per unit			
Residential	-0.225	1 000 000	400 000
Commercial and industrial	-0.10	11 500 000	4 600 000
Subtotal		12 500 000	5 000 000
Total		22 500 000	10 000 000

Let us assume this utility wishes to change its declining rate structure to a single unit rate, anticipating that this will promote water conservation. The new single unit rate would increase the price of water to those large users who currently benefit from the lower volume rate for water in excess of 40 units per month. Total revenue needs remain at $10 million. Therefore, adoption of a single unit rate would result in a price decrease for consumption of 40 or fewer units per month.

Determining the new single unit rate that would satisfy the revenue needs of the utility, given the stated consumer reaction to price, involves solving a quadratic equation algebraically. The solution would be a single unit rate of approximately $0.44. A rate of $0.44 would result in total consumption of 22,602,000 units. In this simplified example water consumption under the single unit rate has increased 102,000 units over the level of consumption under the declining rate structure. This increase is brought about solely by the change from a declining block rate structure to a single unit rate structure.

Total consumption increased because residential customers, the largest group of consumers experiencing the decrease in price, have a relatively higher elasticity of demand (–0.225). Residential consumption will increase more in response to the proposed price decrease than commercial and industrial consumption will decrease in response to the price increase. The reasonableness of the assertion may be intuitively followed by recognizing that the weighted average elasticity of demand in the first consumption block (residential) is –0.20 while the weighted average elasticity of demand in the second consumption block (commercial and

2 C.W. Howe and F.P. Linaweaver, "The impact of price on residential water demand and its relation to system design and price structure", *Water Resources Research*, first quarter 1967.

3 S.H. Sanke and R.K. Davis, "Demand management through responsive pricing", *Journal-AWWA*, vol. 63 No. 9 (September 1971).

4 A.E. Casuto and S. Ryan, "Effect of price on the residential demand for water within an agency", *Water Resources Bulletin*, vol. 15, No. 2 (April 1979).

industrial) is –0.11. The tendency of residential customers, who make up the bulk of consumers who will experience the effective price reduction, is twice as strong to increase consumption as is the offsetting tendency of commercial and industrial customers making up the bulk of consumers in the second consumption block to cut consumption in response to the price increase.

In accordance with this simplified example, consumers in the first consumption block will react to the 12 per cent price reduction ($0.50 price per unit reduced to $0.44 per unit) by increasing consumption by 2.4 per cent or approximately 240,000 units. Consumers in the second consumption block, faced with a 10 per cent price increase ($0.40 per unit price increased to $0.44 per unit), will decrease consumption by 1.1 per cent or 138,000 units. Thus the utility has increased total consumption by approximately 102,000 units.

The mathematical model supporting this conclusion in detail is included in the annex. Consumption in the mathematical model has increased 82,000 units at the equilibrium unit price of $0.44284 as shown in table 2. (The differences between consumption in the simplified example in table 1 and consumption in table 2 are due to rounding.)

Once price elasticity coefficients are known for major customer groups, changes in consumption levels can be calculated for a series of pricing alternatives without resorting to a mathematical model. This enables a utility to calculate the required price through a series of trial-and-error steps. The overriding constraint is that each rate structure must generate the necessary total revenues required to operate and maintain the system. The advantage of the mathematical model is that the theoretical exact unit price necessary to maintain revenues can be calculated in one step.

Declining rates encourage conservation

The impact of the sample utility's going from a declining block rate structure to an inclining block rate structure would be even more dramatic than going to a single unit rate, further increasing total consumption. Moving from a declining rate-block pricing structure to a single unit or inclining block pricing structure will result in increased total consumption whenever the average elasticity of demand for consumption in the higher priced blocks (low consumption block of 0-40 units in the example) is larger than that of consumption in the lower priced blocks (high consumption block of more than 40 units in the example), an almost universal condition in the water industry. As a general rule a price elasticity coefficient of –0.3 is considered to be larger than an elasticity of –0.1 even though –0.3 is numerically smaller than –0.1.

Table 2. Water consumption rates and annual revenues for a utility using a single-unit rate of $0.44284

Rates of Consumption	*Price elasticity coefficient*	*Water sales (units)*	*Annual revenues ($US)*
0 to 40 units			
Residential	-0.225	8 206 000	3 633 900
Commercial and industrial	-0.10	2 023 000	895 800
Subtotal		10 229 000	4 529 700
More than 40 units			
Residential	-0.225	976 000	432 200
Commercial and industrial	-0.10	11 377 000	5 038 100
Subtotal		12 353 000	5 470 300
Total		22 582 000	10 000 000

Although the application of the price elasticity model generates precise quantities of predicted consumption under specific assumed conditions, it should be noted that laboratory conditions are seldom duplicated in real life. Many factors other than price influence water consumption. Price elasticity models, while being reliable expressions of aggregate consumer tendencies, are poor predictors under actual conditions.

Conclusion

Today's utility planner must be aware of the complex economic political, and social environment facing the utility. In addition to being professionally competent, the utility planner must understand the complex interrelationship between the price for water and the demand for water as it affects utility operation. Too close examination of a single tree in a forest (an economic truism) may well preclude the oversight and broader perspective of the managerial view of the whole forest. Water conservation is not a simple issue. Simplistic solutions may not provide the correct answer and will frequently compound the problem.

Annex

The mathematics of the elasticity relationship can be defined and solved by:

$$(R_1 + C_1)\,U - R_1 R_e\, U^{\frac{(P_1 - U)}{(P_1)}} - C_1 C_e\, U^{\frac{(P_1 - U)}{(P_1)}} +$$

$$(R_2 + C_2)U - R_2 R_e\, U^{\frac{(P_2 - U)}{(P_2)}} - C_2 C_e\, U^{\frac{(P_2 - U)}{(P_2)}} = RR$$

RR = required revenue
RR = $10,000,000

R_1 = residential consumption–first block
R_1 = 8,000,000 units

R_2 = residential consumption–second block
R_2 = 1,000,000 units

R_e = estimated residential price elasticity
$R_e = -0.225$

C_1 = commercial and industrial consumption--first block
$C_1 = 2{,}000{,}000$ units

C_2 = commercial and industrial consumption--second block
$C_2 = 11{,}500{,}000$ units

C_e = estimated commercial and industrial price elasticity
$C_e = -0.10$

P_1 = original price--first rate block
$P_1 = \$0.50$ per unit

P_2 = original price--second rate block
$P_2 = \$0.40$ per unit

U = single unit price to generate \$10,000,000
U = unknown

By substituting values for the known variables and by grouping like terms, the equation becomes

$$7437.5\,U^2 - 25\,875\,U + 10\,000 = 0$$

Solving for the unknown

$$U = \$0.44284 \text{ or } \$3.0361$$

The consumption of water at \$0.44284 is 10,000,000/0.44284 = 22,582,000 units. Although two single unit price solutions are possible, the second solution of \$3.04 should be rejected. Price elasticity estimates are only expressions of tendencies toward an expected response to price changes within a reasonable range of the current price, assuming other factors remain constant.

TIPS FOR TRAINING WORKERS IN THE DEVELOPING WORLD: A CONTRACTOR'S VIEW

*H. Richard Wall**

Governments of the developing world have realized that new technology and new manufacturing capability is of little use without a skilled workforce to run and maintain the facilities. Consequently, training programmes are now part of many contractual negotiations for large-scale facilities. To force training of nationals and limit the number of expatriates, many third-world countries limit expatriate visa periods and require expatriates to train nationals as replacements before visas expire.

These requirements have placed tremendous burdens on engineering/construction companies which are often the first firms to begin work in developing countries. American training methods are not applicable to third-world cultures, and construction companies are not accustomed to training workers as a project is being planned and built. Building under these conditions is difficult. First the contractor has to meet a precise schedule of construction, installation and check-out of equipment, while grappling with the engineering procurement, construction management and communications problems which accompany large overseas projects and frequently cause delays. Concurrently, however, the host countries at present expect the firm to carry out an aggressive replacement training programme for their national counterparts, who can number in the hundreds, even thousands.

Frequently, there are not enough nationals with minimum skills to train, for example in Saudia Arabia and Kuwait. When there is serious competition for existing jobs between host country nationals and expatriates, there is often labour unrest which can lead to riots. Finally, once the project is constructed, companies are often expected to convert construction workers to manufacturing workers, capable of operating steel mills, refineries, mines and other operations.

The success of these programmes often depends on how seriously expatriate contractors take their responsibilities for realistic personnel planning and allocation of resources. The first step must be to realize the problems, understand the differences between workers in the developed and developing world, and accept the critical importance of planning.

One traditional training method has been for developing countries to send promising individuals to universities in other countries for training. This is time-consuming and expensive, and has not proved to be a solution to the problem. Once trained, many of these students remain in the host country. Or, students returning to their own country find their skills don't meet their country's needs. Or these students return to administrative rather than field positions, which

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does not alleviate the shortage of trained managers and craftsmen.

In recent years, training programmes have moved towards providing technical skills as fast as possible. It is especially important to provide skills targeted specifically to the needs of the operation. At present, successful training programmes begin years in advance of the project. Operations personnel are sometimes trained in the host countries by working in facilities similar to those planned. Then nationals gain work experience by working in similar facilities in another developing country. Construction/engineering firms either establish the training programme or subcontract to firms that specialize in training.

Important to the success of these programmes and to in-country training is the realization that the programme must be tailored to the workforce. The workers cannot (and should not) adapt to the training methods. Some common problems faced by firms developing training programmes range from language and cultural differences to physical problems.

In the developing world, for example, there is little or no cultural background in scientific technology. Children do not play with toy trucks, build model airplanes or repair bicycles, and therefore, workers are not acquainted with machinery and processes. A Bedouin child shown a photograph of a stream and waterfall will not necessarily know which side to hold upright because he or she may never have seen a waterfall.

Training in the local language is often difficult because the language may not have words for equipment and technology. So the first step in training projects is language training, often involving memorization of English names for equipment. Trainees often have serious health problems which impair learning ability. In Saudia Arabia, for example, many workers have serious visual problems because of water-borne parasites.

The physical details of training are often difficult in the developing world. It is difficult to get facilities and equipment ready in time to train workers, and often equipment imported for teaching appropriated for use at the job site.

Learning methods differ the world over. In some parts of the third world, students are taught to learn by rote. Consequently, managerial trainees, although educated, have not developed problem-solving skills.

Finally, there are attitudinal differences that can be difficult to overcome. In the developing world, employers are often paternalistic, becoming involved in the personal life of workers. American employers are not accustomed to this role. Absenteeism during planting and harvesting times and religious holidays is very high, and it is difficult to keep a training programme on schedule when students miss weeks of classes.

Flexibility in programming

The type of training programme developed depends on the level of sophistication of the trainees and the level of training. In general, the training of managers and supervisors is less expensive because such trainees are better educated and healthy. And it is also less expensive to teach concepts because no equipment or hands-on training is required.

Training of craftsmen is expensive. It costs at least two to three times more to train a craftsman in a developing country than in the United States of America. Teaching is primarily visual, starting with an equipment board with samples of tools of the trade—such as wrenches, saws, hammers—attached. Students first memorize the English names and then become familiar with the tools. Next follows a demonstration phase where use of the equipment or process is repeatedly shown to the students. Then students spend classes working with the equipment and on sample problems to develop fundamental skills. Finally, students move to the job site for on-the-job training. Training courses for craftsmen can run from 3 to 18 months, depending on the students and the level of skills being taught.

Use of models in training is becoming more popular. Like toys, models provide experience with technology that most of these students have not had. One recent advance is an interactive computer programme which translates from Arabic to English to Arabic. The programme allows both an English-speaking instructor and an Arabic-speaking student to work with diagrams, identifying parts and processes in both languages. Of course, this aid is useful only with literate trainees.

Selection of trainees is important. The best method is to generate skill levels by which to select trainees and then develop objective ways to evaluate their accomplishments in the programme. Often, however, competition for jobs is so fierce that the host government insists that companies attempt to train unsuitable workers. The best training programmes use both skilled nationals and expatriates to teach. Again, however, competition on the job site for skilled nationals is such that most are needed to work on the project.

Planning is key to success

The most important ingredient of successful training programmes is intelligent planning. And an important step toward success is to list the needs of the host country (implicit and explicit), the costs of meeting those needs, and the resources available for training. Items to be considered when compiling such a list include:

(a) *Workforce.* Many large contracting firms with third-world experience have done extensive studies of manpower availability, skills levels and health of potential workforce, and demographic studies of many developing countries. Companies without experience in the third world are at a disadvantage because they do not have access to this information and they lack experience in training development.

As part of the primary contract negotiations, most developing countries require the firm to establish a time line which presents the schedule for replacing expatriates with nationals. The time line should be realistic because many governments penalize the firm for failure to replace expatriates as scheduled.

(b) *Facilities.* Are these existing plants, schools or construction sites that can be used for training and co-operative experience? Are there other projects underway where co-training efforts between two firms might be possible? It is important to know before the contract is negotiated how much building and importing of materials for training will be necessary because that influences the training time required.

(c) *Extent of involvement required.* Is the contracting firm expected to provide general guidance for training of nationals, and at what level (craftsmen or managerial)? Or is the company expected to assume full responsibility for complete training and replacement of workers? Can the necessary programme be developed in-house, or is a subcontractor required? Requirements can differ with each project. In Indonesia, the Bechtel Corporation was required to build training centres throughout the country as well as to provide on-the-job-training, both of which they developed in-house. Fluor Corporation provided the same services, but did so by contracting with an American training organization based in Indonesia.

(d) *Goals of the programme.* What does the host country want from the programme? –

(i) managerial development;
(ii) hire employment during construction;
(iii) construction workforce development;
(iv) craftsmen training; or
(v) some combination of the above.

Host countries are not always clear in their demands, and it is important for the success of the training programme that a clear set of priorities be developed at the beginning of the contract negotiations.

(e) *Cost and profits.* Too often the budget for the training programme is an after-thought, and the company loses money. Training programmes can be profit-makers if the programme is well-planned and represented in the primary contract negotiations. Other questions the contracting firm needs to consider are: how will the programme be financied – lump-sum item, charge per student, or a combination? How long should the training process take? What penalities will be levied for failure to replace expatriates with nationals as specified on the time line?

The past 10 to 15 years have brought an increased militancy in the demands of the developing world for increased levels of training. Their aggressive demands have paid off. In Indonesia, there is now a second and third generation of workers, and a skilled workforce is slowly evolving.

Engineering/construction firms may as well accept the need to provide adequate training as a regular part of the third-world projects because governments will bar from consideration those firms that do not provide sound, effective work-force development programmes.

water resourcefulness department: Fishy role in pollution control

'Live' fish reveal dirty water

The Nile pike, which emits electric sparks according to its health, may be used by the sanitation department of the city of Goeppingen, in the Federal Republic of Germany to monitor the quality of the water supply. Up to now the city has used trout and goldfish as indicators of water quality, but the 20 cm-long Nile pike is more accurate.

Its 0.08V pulses are monitored by electrodes fitted to the fish-tank. If the pulse rate of 400 to 800 for a healthy fish drops below a critical point, the flow of water to the city system can be automatically stopped until the situation is corrected.

SOURCE: *Water services*, 1980

Biological control of water weeds

Weeding in irrigation canals at the Coachella Valley Water District in the desert of Riverside County, California, USA, once required tractors, chains and railroad irons. Now weedeating tropical fish have taken over the task, saving several hundred thousand US dollars in the last two years.

University of California, Riverside scientist Fred Legner was the first to show that African perch *(Tilapia)* can clear the canals of the burgeoning mosslike weeds that threaten to choke them each summer. The weeds, which thrive even in the silt of concrete-lined canals, grow as much as 10 cm a day.

The problem is not restricted to the 200 km of canals in the Coachella Valley but also affects 8,000 km of canals in California's low desert, including the Imperial and Palo Verde valleys. Field trials indicate that 5,000 *Tilapia* per surface hectare exert effective weed control but their limited availability has so far restricted their use to the Coachella area. Since the fish die off in winter temperatures they must be restocked every spring. The fish also control mosquitoes and midges, and have significantly suppressed these insect pests in the Coyote Creek drainage of the Los Angeles basin, thereby eliminating the need for chemical treatments.

SOURCE: *University of California, Riverside, Association Bulletin*, October/November 1980 as repr. in *Irrinews* No. 24, 1981

RESEARCH

APPROXIMATE FLOOD ROUTING METHODS: A REVIEW

*P. Erwin Weinmann and Eric M. Laurenson**

The mathematical flood routing models currently available may broadly be classified into process-type models, often called "hydraulic methods", and models using a conceptual or systems approach, commonly referred to as "hydrologic methods". This distinction is appropriate in well-defined regular channels, but for application to natural rivers it may be fallacious, as the complex physical properties of natural river systems defy exact mathematical representation and, therefore, any form of modeling necessarily involves a conceptual element.

Over the years different models in both groups have developed along separate lines, each claiming distinctive features that made it especially suitable for particular applications. Owing to the recent developments in the fields of high speed computers and numerical techniques, process-type models have reached a high level of perfection and are increasingly being used in a wide range of flood routing applications. However, their high demands on computer resources, as well as on quantity and quality of input data, restrict their efficiency in practical applications. Approximate models, on the other hand, produce results at considerably less expense but are limited in their generality and accuracy, their performance depending on the detailed features of the model and the specific application.

The conflicting demands placed on flood routing models have led to the development of a large number of different models, the intricacies of which leave the practitioner somewhat lost. This paper clarifies the situation by summarizing the theoretical background of and the relationships among some of the more important models. It further draws attention to a generalized approximate model that includes most of the well-known approximate flood routing methods as special cases, and may be used as the basic tool for efficient flood routing computations.

Development of flood routing models

In trying to predict the modification of a hydrograph in its passage through a river reach, any flood routing model involves a number of assumptions and simplifications. In order to understand the nature of these simplifications, it is useful to study the different steps involved in the development of a mathematical model for flood routing computations (see figure 1).

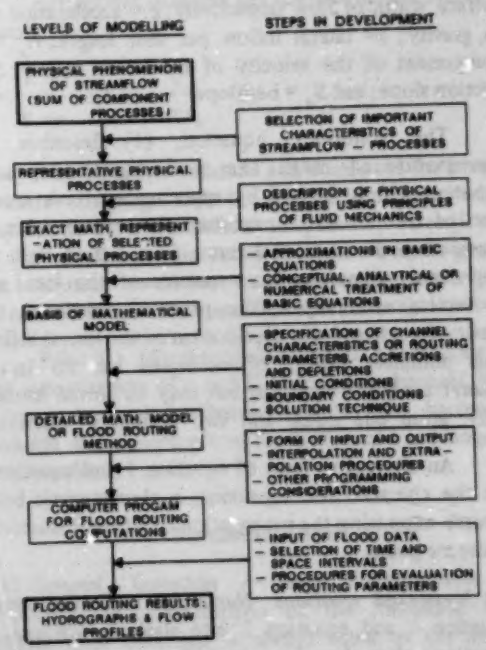
LEVELS OF MODELLING
STEPS IN DEVELOPMENT
PHYSICAL PHENOMENON OF STREAMFLOW (SUM OF COMPONENT PROCESSES)
SELECTION OF IMPORTANT CHARACTERISTICS OF STREAMFLOW – PROCESSES
REPRESENTATIVE PHYSICAL PROCESSES
DESCRIPTION OF PHYSICAL PROCESSES USING PRINCIPLES OF FLUID MECHANICS
EXACT MATH. REPRESENTATION OF SELECTED PHYSICAL PROCESSES
– APPROXIMATIONS IN BASIC EQUATIONS
– CONCEPTUAL, ANALYTICAL OR NUMERICAL TREATMENT OF BASIC EQUATIONS
BASIS OF MATHEMATICAL MODEL
– SPECIFICATION OF CHANNEL CHARACTERISTICS OR ROUTING PARAMETERS, ACCRETIONS AND DEPLETIONS
– INITIAL CONDITIONS
– BOUNDARY CONDITIONS
– SOLUTION TECHNIQUE
DETAILED MATH. MODEL OR FLOOD ROUTING METHOD
– FORM OF INPUT AND OUTPUT
– INTERPOLATION AND EXTRAPOLATION PROCEDURES
– OTHER PROGRAMMING CONSIDERATIONS
COMPUTER PROGAM FOR FLOOD ROUTING COMPUTATIONS
– INPUT OF FLOOD DATA
– SELECTION OF TIME AND SPACE INTERVALS
– PROCEDURES FOR EVALUATION OF ROUTING PARAMETERS
FLOOD ROUTING RESULTS: HYDROGRAPHS & FLOW PROFILES

Figure 1. Development of mathematical model for flood routing computations

The first two steps in figure 1 are very important but unfortunately do not always get sufficient attention. The complex flow phenomena in natural rivers are generally simplified by considering the flow to be one-dimensional and by representing all processes that contribute to the loss of energy or momentum by a single lumped parameter, the frictional resistance coefficient. With some further assumptions this leads to the St. Venant system of equations for one-dimensional gradually varied flow, which is reviewed briefly as the basis of the complete models in the next section.

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The next two steps are important in the classification of models and in distinguishing different forms of approximate models, as explained in later sections.

The last two two steps, though important in practical flood routing computations, are not directly relevant to the subject of this paper and are not examined.

Complete dynamic models

(a) *Basic equations.* The St. Venant equations for gradually varied, unsteady open channel flow may be written as

$$B\frac{\partial y}{\partial t} + \frac{\partial (Av)}{\partial x} - q = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\text{and } \frac{1}{g}\frac{\partial v}{\partial t} + \frac{v\partial v}{g\partial x} + \frac{\partial y}{\partial x} + S_f - S_o + \frac{q}{gA}(v - u_x) = 0 \quad \ldots\ldots (2)$$

in which t = time; x = distance along the channel; y, v, A, and B = depth, velocity, cross-sectional area, and surface width of flow respectively; g = acceleration due to gravity; q = lateral inflow per unit length; u_x = x component of the velocity of the lateral inflow; S_f = friction slope; and S_o = bedslope.

The continuity equation, (1) describes the conservation of mass. The momentum or dynamic equation, (2) is derived by applying Newton's second law of motion and expresses the conservation of momentum. Its individual terms from left to right are respectively dimensionless measures of the local and convective acceleration, the pressure, frictional, and gravity forces, and the acceleration of the lateral inflow. This nonlinear system of equations has no known general analytical solution but may be solved numerically, given one initial and two boundary conditions.

An alternative form of equation 1 and equation 2 are the characteristic equations, a characteristic being a curve expressing the propagation of a flow disturbance in the x-t plane.

(b) *Numerical solutions.* Numerical methods convert equation 1 and equation 2 into algebraic (difference) equations that may be solved for y and v at finite incremental values of x and t. Available methods of doing this can be grouped into four categories: (i) finite difference schemes that solve the characteristic equations for y and v at x-t values defined by the (curvilinear) characteristic grid; (ii) explicit finite difference schemes for the characteristic equations using a rectangular x-t grid; (iii) explicit finite difference schemes for the original equations using a rectangular grid, and (iv) implicit finite difference schemes for the original equations using a rectangular grid. Explicit schemes use explicit equations for y and v at a given x-t point, while implicit schemes use sets of simultaneous equations to find y and v at several x values simultaneously for a given t value.

In each category, mathematical models have been developed to a level satisfying the accuracy requirements of most streamflow routing applications (see annex I, reference No. 12). The models using a characteristic grid (category i), although suited to a wide range of unsteady flow problems, require a large amount of interpolation and place a heavy demand on computer resources. Programming simplicity tends to favor the explicit schemes (ii) and (iii), but in these models the size of the time step, Δt, is limited by the Courant stability condition to

$$\Delta t \leq \frac{\Delta x}{v + \sqrt{gy}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Implicit models (category iv) are not subject to this stability condition. They are further claimed by Amein and Fang (I:1) to be the only schemes suited to deal with large variations in flow characteristics between adjacent channel sections. For routing computations of slowly varying floods in natural rivers with typical durations of several days, implicit models thus appear to be the most efficient.

Approximate models (general)

(a) *Classification of models.* While all flood routing models use the equation of continuity in a similar manner, different groups of models may be distinguished according to the number of terms considered in the momentum equation. Those that retain all the terms are called "complete dynamic models". These have been examined previously. Being the most complete, they are also the most accurate and reliable methods as well as the most demanding on computer resources. Nevertheless, they do not guarantee accurate modeling as they are based on the assumptions made in the formulation of the St. Venant equations. In natural channels these assumptions and the practical application of the model become workable only by using long reaches and regarding the effects of channel irregularities as being included in the empirical roughness coefficient. This renders the model, in application, a conceptual one. It also leads to acceleration terms one to several orders of magnitude smaller than S_o.

Models that, in consequence of this, neglect the acceleration terms are variously called approximate dynamic models, diffusion analogy models, or kinematic models corrected for dynamic effects, depending upon the form in which the equations are expressed.

Adoption of long reaches also greatly reduces the magnitude of the channel irregularity effect on the pressure force term $\partial y/\partial x$. For a reach containing a bend or bends, the bank reaction effects necessarily lumped in with the roughness coefficient must outweigh the pressure force term. This terms, however, is also affected by the flood wave steepness and, for steeply rising hydrographs in flat channels, it can approach S_o. Typically, though, it is an order of magnitude smaller

than S_o and may, in first approximation, be neglected. This leads to the simplest form of the momentum equation

$$S_f = S_o \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

which forms the basis of the *kinematic wave models* and, as will be examined, of a larger class of models that will be called *kinematic models*.

(b) *Rating curve form of momentum equation.* Development of the approximate models is facilitated by manipulating equation 2, the momentum equation, into the form of a rating expression relating Q, indirectly, to y. A general flow formula like the Chezy or Manning formula is used. Thus

$$Q = CAR^m \sqrt{S_f} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

in which C = empirical resistance coefficient; R = hydraulic radius; and m = empirical exponent. For unsteady flow, S_f varies with flood wave slope as well as flow depth. For steady uniform flow, or normal flow Q_n, i.e., when equation 4 applies, Q is a function of depth alone and gives:

$$Q = Q_n = CAR^m \sqrt{S_o} = f(y) \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

For steady flow in irregular channels, the concept of bedslope is not very meaningful and S_o in equation 6 should be interpreted as the friction slope or energy gradient at some reference discharge.

Substituting in equation 5 CAR^m from equation 6 and S_f from equation 2 and neglecting the effects of lateral inflow gives a form of the momentum equation that is a general expression for a *looped rating curve:*

$$Q = Q_n \sqrt{1 - \frac{1}{S_o}\frac{\partial y}{\partial x} - \frac{v}{S_o g}\frac{\partial v}{\partial x} - \frac{1}{S_o g}\frac{\partial}{\partial t}} \quad \ldots\ldots (7)$$

kinematic wave
diffusion analogy
complete dynamic wave

The kinematic wave and diffusion analogy approximations to equation 7 are as indicated.

A looped rating curve is shown diagrammatically in figure 2, with A and B indicating the points of maximum flow rate and maximum flow depth, respectively. The width of this loop, and therefore the order of accuracy achieved by the approximate methods, depends on the magnitude of the secondary terms in equation 7.

Approximate dynamic and diffusion analogy models

This group of models is based on the continuity equation in the following form, which is a variant of equation 1:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

and the indicated part of equation 7. If this nonlinear system of equations is solved directly by the same numerical methods as used with the complete models, the resulting models can be called *approximate dynamic models.*

The two equations can be combined into a single equation of the *convective diffusion type*, expressed either in terms of flow depth (I: 3) or, in a form more convenient for hydrologic purposes, in terms of discharge (I: 6, 14). Thus

$$\frac{\partial Q}{\partial t} + c\frac{\partial Q}{\partial x} = D\frac{\partial^2 Q}{\partial x^2} + cq \quad \ldots\ldots\ldots\ldots\ldots\ldots (9)$$

in which the coefficient c is responsible for the convective (translation) characteristics, whereas the diffusion coefficient D introduces attenuation of the flood wave.

For regular channels the coefficients are evaluated from

$$c = \frac{1}{B}\frac{dQ}{dy} \text{ and } D = \frac{Q}{2BS_o}$$

They may be either constant and computed for a representative discharge, as in the original form proposed by Hayami (I: 3), or variable, as proposed by Price (I: 14). If the coefficients are fitted to observed hydrographs, the diffusion coefficient can account for the effects of channel irregularities and flood-plain storage.

Price (I: 14) proposed analytical expressions for the computation of c and D in irregular channels. With those extensions, diffusion models have become a versatile flood routing tool for both gaged and ungaged river reaches.

Kinematic models

(a) *General.* Equation 7 clearly demonstrates the distinguishing characteristic of the kinematic wave model, that discharge is always equal to the normal discharge and is thus a single-valued function of the depth. The St. Venant equations then reduce to equations 8 and 6. This system can be combined into a single equation, commonly referred to as the kinematic wave equation (I: 11). Therefore

$$\frac{1}{c}\frac{\partial Q}{\partial t} + \frac{\partial Q}{\partial x} = q \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

in which the coefficient 1/c is either constant (linear models) or variable (nonlinear models). The parameter c, describing the travel speed of the flood wave, is called the *kinematic wave speed*, and may, at a particular cross section and for a given Q, be evaluated from the Kleitz-Seddon law. Thus

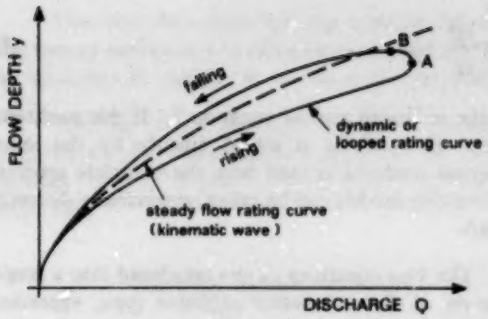

Figure 2. Looped rating curve

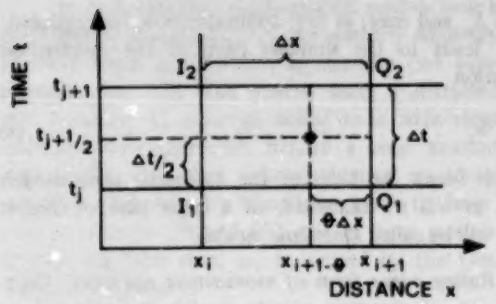

Figure 3. x-t plane: finite difference grid for kinematic models

$$c = \left(\frac{dQ}{dA}\right)_x = \frac{1}{B}\left(\frac{dQ}{dy}\right)_x \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Several models are based on or derived from the kinematic wave equation but are more general in that they account for attenuation effects through the numerical methods used, even though their parameters are evaluated from the steady flow rating expression, equation 6. These might be called "kinematic" models since they are based on concepts of water *movement* as embodied in the continuity equation and neglect consideration of the forces causing that movement, which are embodied in the momentum equation.

(b) *Kinematic wave models.* Kinematic wave models are based on an analytical solution or an accurate numerical solution of equation 10. Kinematic waves travel without attenuation (but with change of shape) at the kinematic wave speed given by equation 11. These models, therefore, do not allow for subsidence of the wave crest.

In order for equation 10 to be equivalent to equations 8 and 6, the derivative in equation 11 must be found by differentiation of the steady flow rating function, equation 6. Different model versions use flow depth, stage, or flow area as the independent variable and express the rating function in a number of different forms, e.g., (i) the equation $Q = ay^b$, that is, a power function, with the coefficients a and b either determined from channel characteristics or fitted to observed hydrographs; (ii) a flow equation such as equation 5; and (iii) an arbitrary form defined by discrete points in a rating table.

Due to the simple form of the kinematic wave equation nonlinear methods may readily be used in its solution. The four principal methods for numerical solution, as examined previously for the complete method, may also be applied to the kinematic wave formulation. However, the stability condition for explicit schemes is now less severe and may be stated as

$$\Delta t \leq \Delta t_c = \frac{\Delta x}{c} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

(c) *Muskingum-Cunge method.* One explicit finite difference scheme proposed by Cunge (I: 2) may be used as basis for a generalized treatment of kinematic models. As indicated in figure 3, the scheme introduces a weighting coefficient θ, in the finite difference representation of the time derivative. Evaluating the finite difference quotients for the space and time derivatives at the point $i + 1 - \theta, j + 1/2$, the kinematic wave equation, equation 10, for zero lateral inflow, may be written in finite difference form as

$$\left\langle\frac{1}{c}\right\rangle \frac{\theta(I_2 - I_1) + (1-\theta)(Q_2 - Q_1)}{\Delta t} + \frac{Q_1 + Q_2 - I_1 - I_2}{2\Delta x} = 0 \quad \ldots (13)$$

in which $\langle 1/c\rangle \cong \langle 1/c\rangle \neq f(t)$; and $\langle c\rangle$ is an average value of c for the reach.

Introducing the travel time parameter $K = \Delta x/\langle c\rangle$, the solution of equation 13 for Q_2 can be reduced to a form identical to the classical Muskingum coefficient equation by McCarthy, equation 14. Thus

$$Q_2 = C_1 I_1 + C_2 I_2 + C_3 Q_1; \text{ where } C_1 = \frac{K\theta + \frac{\Delta t}{2}}{K(1-\theta) + \frac{\Delta t}{2}};$$

$$C_2 = \frac{-K\theta + \frac{\Delta t}{2}}{K(1-\theta) + \frac{\Delta t}{2}}; \quad C_3 = \frac{K(1-\theta) - \frac{\Delta t}{2}}{K(1-\theta) + \frac{\Delta t}{2}}; \text{ and}$$

$$C_1 + C_2 + C_3 = 1 \quad \ldots\ldots\ldots\ldots (14)$$

The value of K is clearly a measure of the translation or storage delay time. It may be determined by observation, analysis of hydrographs, or from the Kleitz-Seddon law (equation 11).

Cunge (I: 2, 12) showed that the Muskingum scheme is a second-order approximation of the diffusion equation if the parameter K is evaluated as $K = \Delta x/\langle c\rangle$ and the parameter θ from

$$\theta = \frac{1}{2}\left(1 - \frac{Q}{BS_o c \Delta x}\right); \quad 0 < \theta < 0.5 \quad \ldots\ldots\ldots\ldots\ldots (15)$$

This expression for the weighting coefficient θ was obtained by Cunge from a Taylor series expansion of $Q(x_i, t_j)$ in the finite difference form of equation 10 and a comparison with the coefficients of the diffusion equation for regular channels.

Equation 15 may be written in terms of Δx, yielding, for $\theta = 0$, the following:

$$\Delta x = \frac{Q}{S_o B c} = \frac{Q}{S_o \frac{dQ}{dy}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15a)$$

i.e., the expression proposed by Kalinin and Milyukov (I: 5, 12) for the computation of the length of the characteristic subreaches into which the overall reach should be divided for routing with $\theta = 0$.

In order to obtain a single representative value of θ or Δx, applicable for the full duration of the routing computations, equation 15 and 15*a* need to be evaluated for a representative value of Q and corresponding values of B and c, or $dQ/(dy)$. In irregular channels these parameters should represent average values for the subreach.

(d) *Generalized kinematic model.* A more exact solution of equation 10 was proposed by Koussis (I: 6) carrying out the discretization in space only and retaining continuous functions for the time derivatives. Using for the time derivative the weighting scheme indicated in figure 3, the kinematic wave equation, equation 10, may be written as an ordinary differential equation as follows:

$$\frac{dQ}{dt} + \frac{1}{\left\langle \frac{1}{c} \right\rangle \Delta x(1-\theta)} Q = \frac{1}{\left\langle \frac{1}{c} \right\rangle \Delta x(1-\theta)} I - \frac{\theta}{1-\theta} \frac{dI}{dt} \quad \ldots\ldots (16)$$

With the same assumption for $\langle 1/c \rangle$ as for equation 13, and assuming linear variation of Q over the time interval, Δt, the solution may be written in a form convient for computation, i.e., as a coefficient equation of the following Muskingum type:

$$Q_2 = C_1 I_1 + C_2 I_2 + C_3 Q_1$$

where the coefficients are now $C_1 = \frac{\Delta x}{\langle c \rangle \Delta t}(1-\beta) - \beta$;

$$C_2 = 1 - \frac{\Delta x}{\langle c \rangle \Delta t}(1-\beta);\ C_3 = \beta \text{ with } \beta = \exp\left(-\frac{\langle c \rangle \Delta t}{\Delta x (1-\theta)}\right)$$

and $C_1 + C_2 + C_3 = 1$ ..... (17)

Some well-known kinematic models can be related to this *generalized kinematic routing model* as follows: (i) With $\Delta x/\langle c \rangle$ replaced by K the model is equivalent to the improved form of the Muskingum model proposed by Nash (I: 13); (ii) with $\Delta x/\langle c \rangle = \tau$ and $\theta = 0$ the model reduces to the Kalinin-Milyukov method (I: 5, 12); and (iii) with $\theta = 0.5$ and $\langle c \rangle$ evaluated from a steady flow rating function the model reduces to a kinematic wave model. Koussis (I: 6) demonstrated that this model is a second-order approximation to the diffusion analogy model if

$$\theta = 1 - \frac{r}{\ln\left(\frac{\lambda + 1 + r}{\lambda + 1 - r}\right)};\ 0 < \theta < 0.5$$

where $r = c\frac{\Delta t}{\Delta x}$ and $\lambda = \frac{Q}{BS_o c \Delta x}$ ..... (18)

(c) *Parameters of the kinematic models.* From the foregoing it is evident that the classification of kinematic models depends on the computation of the routing coefficients and therefore on the selection of the parameters Δx, Δt, θ, and $\langle c \rangle$. The first three of these are examined in this section and the fourth in a later section.

(i) *Parameter* Δx. In the original Muskingum method Δx was made equal to the total length of the routing reach but Laurenson (I: 8) showed that for long river reaches a single-valued storage function could not be obtained and storage routing could only be performed by dividing the total reach into N subreaches of length Δx. Laurenson (I: 9) further showed that N (or Δx) and the weighting parameters θ are not independent of each other, the appropriate value of θ decreasing with Δx, i.e., as the storage becomes less distributed. Since θ may not realistically decrease below zero, there is a limit to the allowable degree of subdivision, which implies a *lower limit* on Δx.

Nash (I: 13) pointed out that unrealistic negative outflows at the beginning of the outflow hydrograph were a necessary consequence of applying the Muskingum method to distributed storages, i.e., those with $\theta \neq 0$. Experience suggests that, for practical purposes, these negative outflows are small enough and sufficiently short-lived to be ignored if

$$K = \frac{\Delta x}{\langle c \rangle} \leq \frac{T_r}{2\theta} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (19)$$

in which T_r = period of rise of inflow hydrograph. This constitutes an *upper limit* on Δx for cases where $\theta \neq 0$.

(ii) *Parameter* Δt. A theoretical upper limit for Δt is given by the stability condition, equation 12. However, in practical applications values of Δt several times larger than Δt_c have been used without any apparent stability problems.

Values of $\Delta t << \Delta x/\langle c \rangle$ imply that the variables at the current section are evaluated before any disturbance at the previous section has been able to travel the distance Δx. For $\theta \neq 0$ this may lead to unrealistic results, i.e., a dip in the outflow hydrograph or, in the case of zero initial flow, to negative outflows. The ideal time step for kinematic models is, therefore

$$\Delta t \cong \Delta t_c = \frac{\Delta x}{\langle c \rangle}$$

but smaller values can be expected to give satisfactory results.

(iii) *Parameter* θ. Cunge (I: 2) compared his numerical solution with an analytical solution of equation 10 and showed that for all values of $\Delta x/\Delta t$, a value of the weighting coefficient $\theta = 0.5$ resulted in pure *translation* of the wave (i.e., kinematic wave behavior), corresponding to fully *distributed* storage. Values of $\theta < 0.5$ introduced numerical distortion, similar to a diffusive term, thus leading to an *attenuation* of the flood wave. A value of $\theta = 0$ corresponds to a fully *concentrated* or reservoir type action where inflow causes an instantaneous response, the principal effect being attenuation of the inflow peak. (The case of $\theta < 0.5$, resulting in amplification of the flood wave, is not of importance for the routing of natural flood waves.)

By choosing an appropriate value of θ between zero and 0.5, the two phenomena of attenuation and translation may be treated simultaneously, subject to the limits on Δt and Δx previously examined. On the other hand, translation effects may be simulated by putting an appropriate number of concentrated storages in series, i.e., by using N subreaches with length Δx given by equation 15*a* and with $\theta = 0$, as in the Kalinin-Milyukov method or in the nonlinear storage routing method incorporated in Laurenson's runoff routing models. A similar effect can be achieved when the two phenomena are treated separately, as in the lag and route models, where the inflow is first translated and then routed through a reservoir.

Except where the weighting coefficient varies greatly with discharge (e.g., in flood-plain flow) the variation of θ will not seriously affect the routing results. It is therefore convenient to use a constant value of θ, evaluated as a representative value for both the length of the subreach and the range of discharges encountered.

The difference between the values of θ computed from equations 15 and 18 is small and for practical applications the simpler expression in equation 15 is sufficient.

Although the coefficient equations were derived under the assumption of constant coefficients, implying a linear model, Laurenson (I: 9) and Koussis (I: 6) among others have been successful in using variable coefficients, implying nonlinearity, at least as long as these coefficients are weakly variable.

An important distinction between different kinematic routing models arises from the way in which the routing parameters are evaluated. If they are directly related to channel characteristics, i.e., computed at *cross sections*, the models are generally termed *hydraulic models* and may, at least for nearly prismatic channels, be applied in ungaged reaches as long as the appropriate roughness parameter can be estimated. If, on the other hand, the parameter determination is based mainly on hydrologic observations for *channel reaches*, the kinematic models are known as *storage routing models*. Although these were developed as conceptual models with empirically determined storage functions, the direct relationship between the steady flow rating function $Q = f(y)$ and the storage function $Q = f(A\Delta x)$ provides a physical basis to the storage routing models. These models are therefore not distinguished from other kinematic models by their physical or mathematical basis, but only by their form and the procedures used for the evaluation of their parameters.

Kinematic model corrected for dynamic effects

(a) *Background and model development*. In the original presentation of the coefficient methods described above, the kinematic wave speed parameter $\langle c \rangle$ for a given reach, though sometimes considered variable with depth (nonlinearity), was a function of depth only. This implied a single-valued rating curve insofar as the evaluation of $\langle c \rangle$ was concerned, and the attenuation effects arose only through the adoption of $\theta < 0.5$. Similarly, storage methods use a single-valued storage-discharge relation.

Several attempts have been made to make these models more general by allowing for a looped rating curve, rather than the single-valued rating curve characteristic of the kinematic wave model, in the determination of the travel speed parameter. Henderson (I: 4) and Williams (I: 16) have done this but the writers adopt the approach developed by Koussis (I: 6).

In cases where the acceleration terms are insignificant a convenient expression for the looped rating curve is given by the "Jones formula" derived from the relevant part of equation 7 using the principles of kinematic wave theory. Thus

$$Q = Q_r \sqrt{1 + \frac{1}{cS_o}\frac{\partial y}{\partial t}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (20)$$

Following Koussis' proposal, equation 20, or an equivalent expression in terms of $\partial Q/\partial t$, is used in the nonlinear kinematic model equation 17 to compute, for a given time interval (in an inner iterative cycle), the relevant segments of looped rating curves at the upstream and downstream ends of the current subreach. The slopes of these looped rating curve segments yield an improved estimate of the travel speed parameter $\langle c \rangle$ for the subreach. Where required, the looped rating curves are also used to convert flow depths into discharge values and vice versa. In the programming, restrictions are needed to prevent numerical instabilities or inaccuracies near the tip of the looped rating curve.

For the downstream section the unknown discharge value at the end of the time interval is determined (in an outer iterative cycle) from the coefficient equation for kinematic models, equation 17, in the same way as for other nonlinear models.

Koussis used the term "approximate dynamic" to characterize this model but as it is to some extent based on kinematic wave theory and has only one set of characteristics, it might more appropriately be described as a *kinematic model corrected for dynamic effects.*

(b) *Hierarchy of kinematic models.* The kinematic model corrected for dynamic effects is the most general of all the kinematic models. Most of the well-known approximate routing models may be treated as special cases of it (figure 4). *Nonlinear models* of the *Muskingum-Cunge,* the *kinematic wave,* or the *Kalinin-Milyukov* type are obtained by omission of the inner iterative cycle for the looped rating curve and by using specific parameter selection procedures. For *linear models* of this type, the outer iterative cycle is also omitted. *Concentrated and distributed models* may be distinguished depending on the number of subreaches and the value of the weighting coefficient θ used. In particular, for $\theta = 0.5$ an efficient variation of the *kinematic wave models* is obtained.

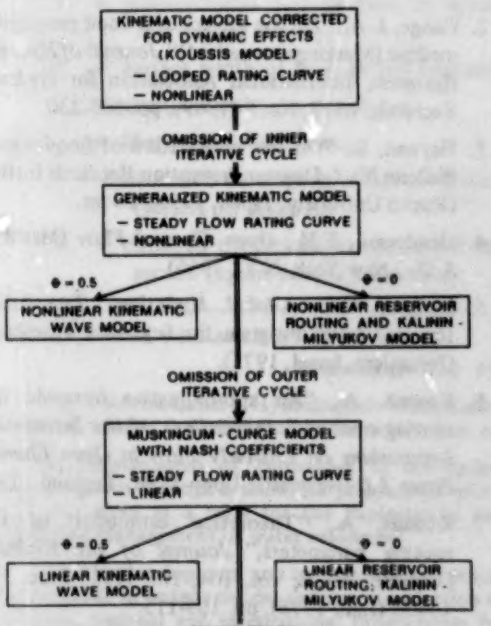
KINEMATIC MODEL CORRECTED FOR DYNAMIC EFFECTS (KOUSSIS MODEL)
– LOOPED RATING CURVE
– NONLINEAR
OMISSION OF INNER ITERATIVE CYCLE
GENERALIZED KINEMATIC MODEL
– STEADY FLOW RATING CURVE
– NONLINEAR
θ = 0.5
θ = 0
NONLINEAR KINEMATIC WAVE MODEL
NONLINEAR RESERVOIR ROUTING AND KALININ - MILYUKOV MODEL
OMISSION OF OUTER ITERATIVE CYCLE
MUSKINGUM - CUNGE MODEL WITH NASH COEFFICIENTS
– STEADY FLOW RATING CURVE
– LINEAR
θ = 0.5
θ = 0
LINEAR KINEMATIC WAVE MODEL
LINEAR RESERVOIR ROUTING: KALININ - MILYUKOV MODEL
SINGLE REACH
MUSKINGUM METHOD WITH NASH COEFFICIENTS

Figure 4. Relationships among various kinematic models

Modeling efficiency

(a) *Order and effect of approximations.* The magnitudes of the individual terms of the momentum equation vary with the inflow hydrograph and the channel properties. For a point about midway on the rising limb of the inflow hydrograph shown in figure 5 and for two typical prismatic channels with identical cross section and frictional properties but different bedslopes the magnitudes of the terms in the momentum equation have been computed as shown in table 1. The rating curve for channel type 2 is characterized by a well-developed loop. The table also shows the errors in the peak flows associated with the omission of terms in the basic routing equations (computed from a complete dynamic model with appropriate modifications). These results demonstrate clearly that: (i) The omission of the acceleration terms in approximate models will not significantly affect the accuracy of the flood routing results in normal circumstances; (ii) for slowly rising hydrographs and moderately steep channels a model that omits the pressure term, i.e., a model of the kinematic wave type, can be expected to give results that differ only slightly from the ones obtained with the kinematic model corrected for dynamic effects, or even with a complete dynamic model; and (iii) in channels of flat grade or with steep hydrographs, or both, the pressure term is significant and the use of a more complex model will be warranted. This fact is shown in figure 5 that compares the performance of three nonlinear kinematic models for the example of channel type 2.

Table 1. Magnitude of terms in momentum equation

Variables (1)	*Channel type 1* (2)	*Channel type 2* (3)
Bed slope	2.0×10^{-3}	0.2×10^{-3}
Pressure term	-0.06×10^{-3}	-0.17×10^{-3}
Local acceleration	0.025×10^{-3}	0.014×10^{-3}
Convective acceleration	-0.023×10^{-3}	-0.013×10^{-3}
Error in computed peak flow due to ommission of *acceleration terms*	<0.1%	1.4%
Error in computed peak flow due to omission of *pressure term and acceleration terms*	0.2%	24.6%

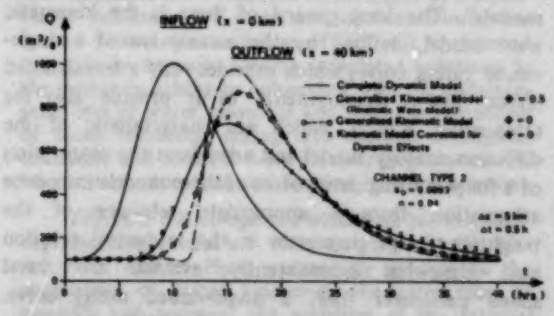

Figure 5. Performance of kinematic models (channel type 2)

(b) *Model flexibility*. Apart from the factors mentioned previously, the selection of the most appropriate model version depends on the amount, format and quality of the available input information, and the desired accuracy and form of the routing results. In some applications the channel characteristics will be defined directly by cross-sectional properties (hydraulic approach); in others the channel characteristics or routing parameters will be more conveniently obtained from observations on channel reaches (hydrologic or storage routing approach). If the hydraulic approach is adopted, input and output of hydrographs may be in the form of either discharge or flow depth. Considerable economies in computer time and in the preparation of input data can be achieved if the flood routing programme to be used is flexible enough to allow a matching of the model complexity and the input and output options to the specific demands of a particular flood routing application. The hierarchic structure of kinematic models facilitates the development of a *general model for approximate flood routing computations*. As shown in figure 4 the kinematic model corrected for dynamic effects includes most of the simpler kinematic models as special cases; they are obtained by omission of iterative cycles or specific selection of parameter values, or both.

A flexible programme allowing the user to select the kinematic model version and the input and output options that best suit the specific needs of his application has been developed and used successfully.

Conclusion

The numerous approximate routing models available, including "hydraulic" and storage methods, are all essentially variants of either the kinematic wave or the diffusion analogy models. None of the approximate methods accounts for acceleration effects. Practically all of the differences between the various approximate methods arise from the degree of generality of their parameters and the method of evaluating them. Parameter identification is of crucial importance in any flood routing application.

The models based to some extent on kinematic wave theory have been called here "kinematic routing models". The least general of these is the kinematic wave model, defined by the assumption of a single-valued rating curve, which provides only a translational effect. Many developments of it provide also for attenuation effects, which are characteristic of the diffusion analogy model and arise from the assumption of a looped rating curve. Most of these models introduce attenuation through appropriate selection of the weighting factor parameter in the numerical solution but, somewhat inconsistently, evaluate the travel speed parameter from a single-valued rating curve. They include the storage methods. With appropriate parameter selection they are equivalent to diffusion analogy models.

Of all the approximate methods, the one typified by the Koussis model is the most general. By providing for a looped rating curve in its parameter evaluation and in the conversion of flow depth to discharge values, it surpasses the diffusion analogy models.

The complete dynamic model is the only satisfactory one where acceleration effects or downstream disturbances are important but, as for all other methods, its success depends upon appropriate selection of an empirical parameter to fit its idealization to the real river reach. Approximate models produce satisfactory results with less expense if their parameters can be well chosen.

A general computer programme based on Koussis' model and allowing efficient flood routing computations by appropriate selection of model version and complexity has been written and used successfully by the first writer. A detailed treatment of all the material of this paper together with routing results and interpretation thereof has been given by the first writer (I: 15).

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Annex II. NOTATION

The following symbols are used in this paper:

A = cross-sectional area of flow, in square feet (square meters);

B = surface width of flow, in feet (meters);

C = empirical resistance coefficient;

C_1, C_2, C_3 = Muskingum coefficients;

c = kinematic wave speed, in feet per second (meters per second);

D = diffusion coefficient, in square feet per second (square meters per second);

g = acceleration due to gravity, in feet per second^2 (meters per second^2);

I = inflow discharge, in cubic feet per second (cubic meters per second);

K = storage delay time, in hours;

m = empirical exponent, dimensionless;

N = number of reaches, dimensionless;

n = Manning roughness coefficient;

P = wetted perimeter, in feet (meters);

Q = discharge, outflow discharge, in cubic feet per second (cubic meters per second);

Q_n = normal flow discharge, in cubic feet per second (cubic meters per second);

q = lateral inflow per unit length, in square feet per second (square meters per second);

R = hydraulic radius, in feet (meters);

S_o = bed slope, normal flow slope, dimensionless;

S_f = friction slope, dimensionless;

T_r = period of rise of inflow hydrograph, in hours;

t = time, in hours;

u_x = velocity of lateral inflow, component in x-direction, in feet per second (meters per second);

v = velocity of flow, in feet per second (meters per second);

x = distance along channel, in feet (meters);

y = depth of flow, in feet (meters); and

θ = weighting coefficient, dimensionless.

HYDROLOGICAL RESEARCH BY UNESCO

Programme for 1981-1983 (second phase)

The International Hydrological Programme (IHP) of UNESCO includes activities which aim at:

(a) Improvement of knowledge of the hydrological system through a scientific programme which will also serve as a basis for the exploitation and integrated management of water resources;

(b) The development and improvement of teaching methods in water sciences and the organization of national, regional and international programmes for the development of water resources and for demonstrating the importance of these resources to social and economic development; and

(c) The strengthening of Member States' institutional infrastructures in the sphere of water resources, with a view to increasing their capacity to evaluate their water resources and manage them scientifically.

The first six-year plan of IHP ended in 1980. The new lines of emphasis in the second phase on this programme (1981-1983) take account of the recommendations of the United Nations conferences on water (at Mar del Plata, 1977) desertification (1977) and science and technology for development (1979). The new emphases are a response to the needs of Member States' economic and social development. During this second phase, the activities of IHP will be directed increasingly towards seeking integrated solutions to the problems arising in connexion with the multipurpose uses of water resources and with the protection of those resources, taking into account ecological, economic and social factors. Greater importance will be given to education and training in water sciences.

UNESCO will co-operate with other international organizations concerned with carrying out the Mar del Plata Action Plan, particularly as regards the assessment of water resources, the promotion of research and training, the activities of the International Drinking Water Supply and Sanitation Decade, and the World Climate Programmes.

STATISTICAL ANALYSIS OF HYDROLOGIC CRITICAL DROUGHTS

Zekâi Şen[1]

One of the fundamental issues in any water-resources-system design and operation is to identify droughts that are likely to occur during the projected life of that system. The extreme values of droughts play an important role in the future performance of any water-resources system, and they give rise to economic losses to society. Since droughts are natural phenomena, their occurrences cannot be predicted with certainty, and thus they must be treated as random variables that can be investigated by the theories of probability and stochastic processes.

Although extensive literature exists on the mathematical modeling and simulation of various hydrologic phenomena, such as rainfall, streamflow, snowmelt, groundwater, their drought properties have been investigated only to a relatively lesser extent due to mathematical intractibility. Rare occurrences, such as critical droughts, have been studied by approximate analytical methods only for independent processes by Feller[2] on the basis of the theory of recurrence events. An extensive simulation study performed by Millan and Yevjevich[3] provides some empirical findings about the probabilities of observed droughts in a Markovian hydrologic sequence.

In this paper, the drought-generating mechanism is abstracted from an observed time series and simple analytical formulation of the probabilistic behavior of extreme droughts is explicitly provided by making use of the stationary Markov processes on the basis of the theory of extremes of random number of random variables combined with the theory of runs. The validity of all derived formulas are checked against the extensive computer simulations.

Finally, applications of the proposed drought model and extreme drought properties derived thereof are given for four annual streamflow sequences observed in various parts of the world.

Drought concept

(a) *Definition.* It is difficult to give a universal definition for drought since there exist widely diverse views about the interpretation of droughts among the scientists of different disciplines. However, herein a drought is basically regarded as a deficit of water in time. In this context, a drought is the deficiency in water supply over a significant time to meet the demand necessary for various human activities. The deficiencies are determined herein with respect to annual flows.

An objective and quantitative definition of droughts has been given first by Yevjevich[4] on the basis of runs theory and stationary time series. Truncation of such a series x_i at constant truncation level x_o yields distinct events of surplus ($x_i > x_o$) and deficit ($x_i \leq x_o$) along the time axis as shown in figure 1(*a*). Any uninterrupted sequence of deficits coincides with a drought of length equal to the number of deficits within the same sequence. Hereafter, this length, in years, will be referred to as drought duration or negative run length. In figure 1(*a*), L_j show the drought durations within the time series considered. The truncation level can be regarded as a constant demand level that can also be given by its probability quantiles as $q = P\{x \leq x_o\}$.

The sum of deficits contained within a drought duration might be employed as an indicator of drought severity, and it will be referred to as the deficit sum in this paper. Every drought duration has associated with it a deficit sum, denoted by D_j in figure 1(*a*). The critical drought concept used in practice usually coincides with the maximum deficit sum in the historic record available. As is evident from figure 1(*a*), the maximum deficit sum does not necessarily possess the longest drought duration, and, therefore, the planner might be confronted with a choice between the two alternatives. Such a choice must be made according to the over-all objective of the project, i.e., in an agricultural project long drought durations with small deficit sums are expected to be more hazardous to plant life than a drought with a maximum deficit sum of relatively short duration. In such a situation the longest drought duration is of prime importance, and, consequently, it is adopted as an indicator of critical drought. However, in water supply, hydroelectric power generation, and waste-water discharge into a water body, the maximum deficit sum must be adopted as critical drought.

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2 W. Feller, *An Introduction to Probability Theory and Its Applications*, vol. 1 (John Wiley and Sons, Inc., New York, N.Y., 1957).

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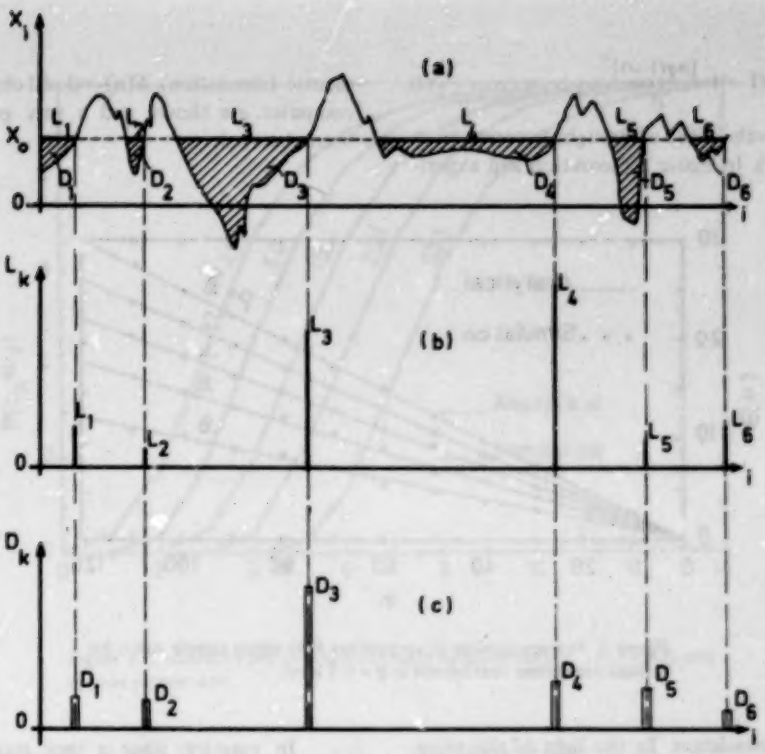

Figure 1. (a) Truncation of given series x_i at x_o level; (b) Drought durations sequence; (c) Deficit sums sequence

(b) *Statistical properties.* Since droughts are contained in an observed sequence of random chcracter, they themselves are random and therefore have distribution functions. If the observed sequence is found to come out of an independent process, then the probability of a drought duration less than or equal to an integer j value was shown by Feller as

$$P\{L \leq j\} = 1 - q^{j-1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

in which q = nonexceedence probability $P\{x < x_o\}$ with truncation level x_o. Similarly, for the lag-one Markov process the probability of drought period is given by the writer[5] as

$$P\{L \leq j\} = 1 - r^{j-1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

in which r = conditional probability $P\{x_i \leq x_o | x_{i-1} \leq x_o\}$ and is given in tables presented in Ref. 4 for various truncation levels and first-order serial correlation coefficients ρ.

The distribution of deficit sums is very complex to obtain even for independent process but their low-order moments are given in Downer *et al.*[6] and for dependent processes in Şen[7].

5 Z. Şen, "Wet and dry periods of annual flow series", *Journal of the Hydraulics Division*, ASCE, vol. 102, No. HY10, Proc. Paper 12457 (October 1967), pp. 1503-1514.

6 R.N. Downer, M.M. Siddiqui and V. Yevjevich, "Application of runs to hydrologic drought", *Proceedings*, International Hydrology Symposium (Fort Collins, Colorado, 1967).

7 Z. Şen, "Run sums of annual flow series", *Journal of Hydrology*, vol. 35 (1977).

Mathematical model of droughts

(a) *Model abstraction.* A careful consideration of figure 1(*a*) stimulates one to gain some insight into the possible mathematical model of droughts along the following properties: (i) There are random number k of droughts within the given sequence at any truncation level; and (ii) the duration and severity of any drought are also random. These two points lead to the conclusion that droughts can be described as random number of random variables. A conceptual representation of drought durations and severities are given in figures 1(*b*) and 1(*c*), respectively. In these representations each one of the upcrossing points where ($x_i \leq x_o$, $x_{i-1} > x_o$) in figure 1(*a*) are taken as time of drought occurrences in figures 1(*b*) and 1(*c*). The choice of upcrossings as drought occurrences is entirely arbitrary, and if, instead, the downcrossings were chosen, there would be no difference in the model behavior since the number of upcrossings and downcrossings are practically the same. In figures 1(*a*) and 1(*b*) each one of the drought occurrence points are assumed to be associated with instantaneous impulses of magnitude equal to the corresponding drought durations (severities).

An important property of successive drought impulses L_j or D_j is that they are entirely independent from each other at any truncation level. The probability distribution function (pdf) of the number of drought occurrences at any trucation level during time interval $(0, n)$ can be shown to be in accord with the Poisson distribution with an average rate of occurrences equal to $n\,q(1-r)$. Thus

$$P\{N_n = i\} = \exp[-nq(1-r)]\,\frac{[nq(1-r)]^i}{i!} \quad \ldots\ldots\ldots\ldots (3)$$

in which expected value $E(n)$ of drought occurrences is equal to $nq(1-r)$. In figure 2 theoretical and experimental (simulation) $E(n)$ values obtained on a digital computer are shown and a very good agreement has been observed.

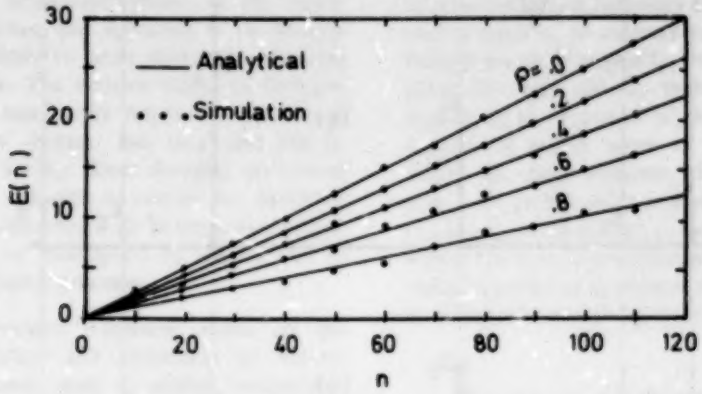

Figure 2. Average number of upcrossings $E(n)$ versus sample size n for various correlation coefficients at $q = 0.5$ level

(b) *Model formulation.* In the light of the aforementioned explanations it can be concisely stated that the problem of critical drought is, in fact, equivalent to the problem of seeking the extreme of random number of random variables, the theory of which has been first introduced into hydrology by Todorovich.[8] Mathematically, longest drought duration L_n and maximum deficit sum D_n in an observed sample of length n can be written as

$$L_n = \max_{0 \le j \le k} (L_j) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

and $$D_n = \max_{0 \le j \le k} (D_j) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

respectively. On the basis of these definitions it follows that both L_n and D_n are stochastic processes of non-decreasing step realizations, i.e., $L_n \le L_{n+1}$ and $D_n \le D_{n+1}$ for all n values.

In practice, since a time series is often treated as a discrete-time, continuous-state process, the longest drought duration assumes integer random variables whereas maximum deficit sum assumes continuous random variables. If the number of upcrossings in time interval $(0, 1)$ is denoted by N_j, then $N_i \le N_j$ provided that $j > i$. Furthermore, if the event of i drought incidences in a fixed time interval $(0, n)$ is denoted by E_i^n, then by virtue of mutual exclusiveness of distinct events $E_i^n \cap E_j^n = \phi$ and $\bigcup_{i=0}^{n} E_i^n = \Omega$ in which ϕ and Ω are empty and universal sets, respectively. In general, the probability that longest drought duration $P\{L_n \le j\}$ will be less than or equal to given duration j can be written by considerations from the extreme values of random number of independent random variables in the Todorovich reference as

$$P\{L_n \le j\} = P\{N_n = 0\} + \sum_{i=1}^{\infty} [P\{L \le j\}]^i P\{N_n = i\} \quad \ldots (6)$$

Furthermore, the substitution of equation 3 into equation 6, after some algebra, leads simply to $P\{L_n \le j\} = \exp\{-nq(1-r)[1 - P\{L \le j\}]\}$ or, more succinctly

8 P. Todorovich, "On some problems involving a random number of random variables", *Annals of Mathematical Statistics*, vol. 41 (1970).

Table 1. Expected value of longest drought duration

	TRUNCATION LEVEL, $q = 0.5$											
	$\rho = 0.0$			$\rho = 0.1$			$\rho = 0.2$			$\rho = 0.3$		
Sample length, n (1)	Analytical (2)	Simulation (3)	Difference (4)	Analytical (5)	Simulation (6)	Difference (7)	Analytical (8)	Simulation (9)	Difference (10)	Analytical (11)	Simulation (12)	Difference (13)
25	3.97	3.97	0.00	4.22	4.23	−0.01	4.47	4.51	−0.04	4.75	4.86	−0.11
50	4.98	5.00	−0.02	5.32	5.35	−0.03	5.68	5.75	−0.07	6.10	6.20	−0.10
100	5.98	6.06	−0.08	6.42	6.48	−0.06	6.89	7.00	−0.11	7.45	7.60	−0.15
200	6.98	7.03	−0.05	7.50	7.34	0.16	8.10	8.10	0.00	8.80	8.94	−0.14
500	8.29	8.25	0.04	8.97	9.05	−0.08	9.71	9.82	−0.11	10.56	10.81	−0.15

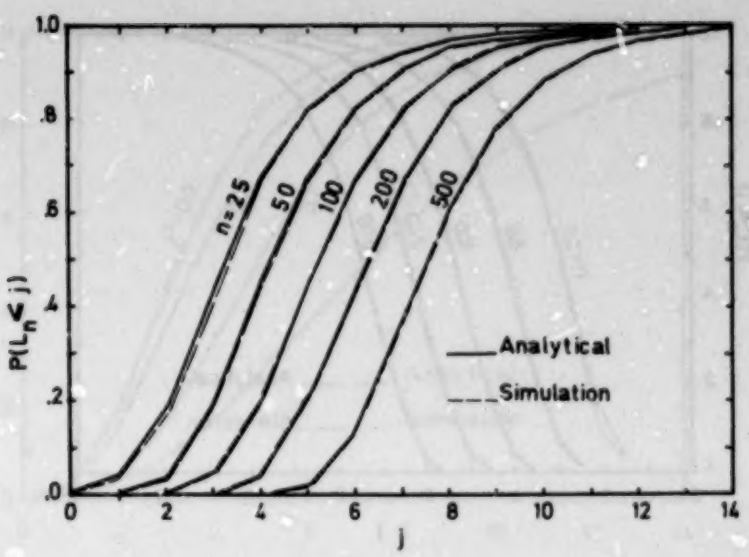

Figure 3. Cumulative pdf of longest drought duration for $q = 0.5$, $\rho = 0.0$, and various sample sizes

$$P\{L_n \leq j\} = \exp[-n\,q(1-r)\,P\{L > j\}] \quad \ldots(7)$$

Since, $P\{L_n = j\} = P\{L_n \leq j+1\} - P\{L_n \leq j\}$, the probability of longest drought duration to be equal to an integer j value can be written as

$$P\{L_n = j\} = \exp[-n\,q(1-r)P\{L > j+1\}] - \exp[-n\,q(1-r)\,P\{L > j\}] \quad \ldots(8)$$

Furthermore, by making use of equation 2, one can write equation 8 more explicitly as

$$P(L_n = j) = \exp[-n\,q\,(1-r)\,r^{j-1}]\,(\exp[n\,q\,(1-r)^2\,r^{j-1}] - 1) \quad \ldots(9)$$

In particular, $r = q$, which corresponds to an independent process representing the original time series equation 9, reverts to

$$P(L_n = j) = \exp(-n\,p\,q^j)[\exp(n\,p^2\,q^j) - 1] \quad \ldots(10)$$

More specifically, if the original time series is truncated at the median level for which $p = q = 1/2$, then equation 10 simplifies to

$$P(L_n = j) = \exp\left(\frac{-n}{2^{j+1}}\right)\left[\exp\left(\frac{n}{2^{j+2}}\right) - 1\right] \quad \ldots(11)$$

Probability distribution function of maximum deficit sum $P\{D_n \leq s\}$ to be less than or equal to any s value can be obtained in the same way as

$$P(D_n \leq s) = \exp[-n\,q\,(1-r)[1 - P(D > s)]] \quad \ldots(12)$$

or $P(D_n \leq s)$

$$= \exp[-n\,q\,(1-r)\,P(D > s)] \quad (0 \leq s \leq +00) \quad \ldots(13)$$

in which $P\{D \leq s\}$ = the pdf of deficit sums to be less than or equal to a given s value.

Numerical solutions and simulations

(a) *Longest drought length.* The solution of equation 9 can be achieved on a digital computer for various truncation levels and first-order serial correlation coefficients. It is also possible to resort to experimental method using simulation to check the validity of derived analytical expressions. Most of the simulation results used in this paper were previously performed by Millan and Yevjevich for sample sizes of n = 25, 50, 100, 200, and 500 and for ρ = 0.0, 0.1, 0.2, and 0.3 at truncation levels equal to q = 0.5, 0.4, 0.3, and 0.2.

For an objective assessment of the agreement between the aforementioned analytical and simulation studies the expected values of longest drought duration are presented in table 1. It is obvious from this table that the absolute differences between analytical and simulation results are very small ranging from 0 to 0.16. On the other hand, figure 3 shows the cumulative pdf of the longest drought duration observed in various sample sizes for $\rho = 0.0$ and $q = 0.5$. Very close agreement between simulation and analytical distribution functions prove the effectiveness of simple and analytical expressions derived in this paper. Figure 4 exhibits the same type of pdf except for $\rho = 0.3$. In figure 5 the cumulative pdf of the longest drought duration in an independent process with sample length of 25 are

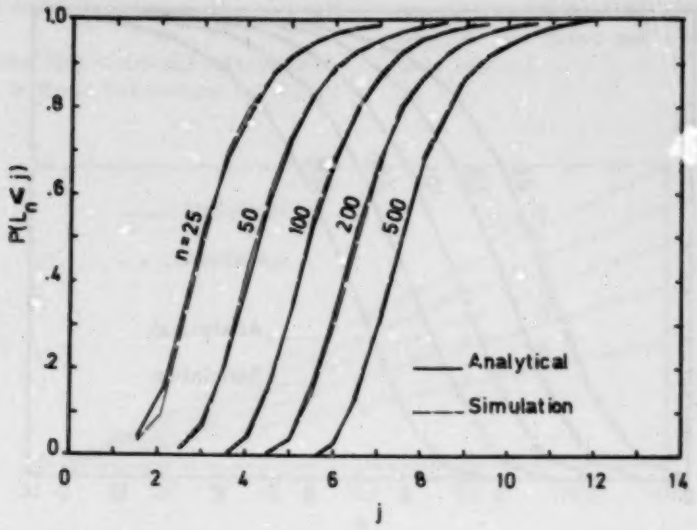

Figure 4. Cumulative pdf of longest drought duration for $q = 0.5$ and $\rho = 0.3$

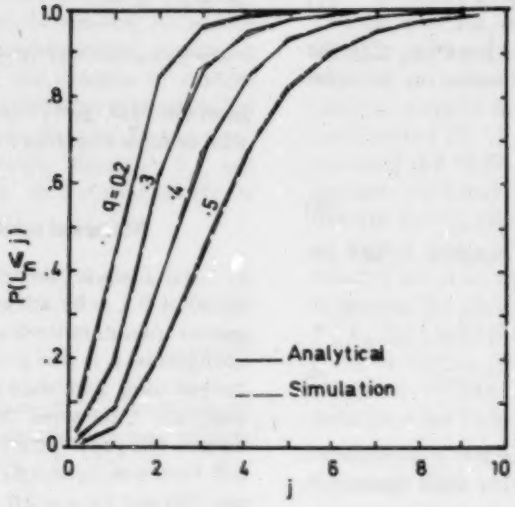

Figure 5. Cumulative pdf of longest drought duration for $n = 25$, $\rho = 0.0$, and various truncation levels

presented for various truncation levels. This figure shows that as the truncation level increases, so does the critical drought duration to be expected in the same sample size. Figure 6 shows the effect of dependence on the critical drought duration. As is evident from this figure, provided that the sample size and truncation level remain the same, increases in correlation coefficients cause critical drought duration to increase. This is the reason why drought properties are regarded as directly related to the autocorrelation structure of the underlying generating mechanism of the hydrologic phenomenon considered.

(b) *Maximum deficit sum.* The pdf of deficit sum D_j over a drought duration is very difficult to obtain exactly. Even for the simplest case of independent processes there exist no analytical solution to this pdf. However, a promising approximate method has been employed herein as follows. Since the deficit sum is a summation of random variables by virtue of the central limit theorem, its distribution can be approximately given by a normal pdf. The mean and variance of this distribution are related to the mean and variance of deficits that are given in the Şen reference (foot-note 7) for the underlying standard normal pdf as

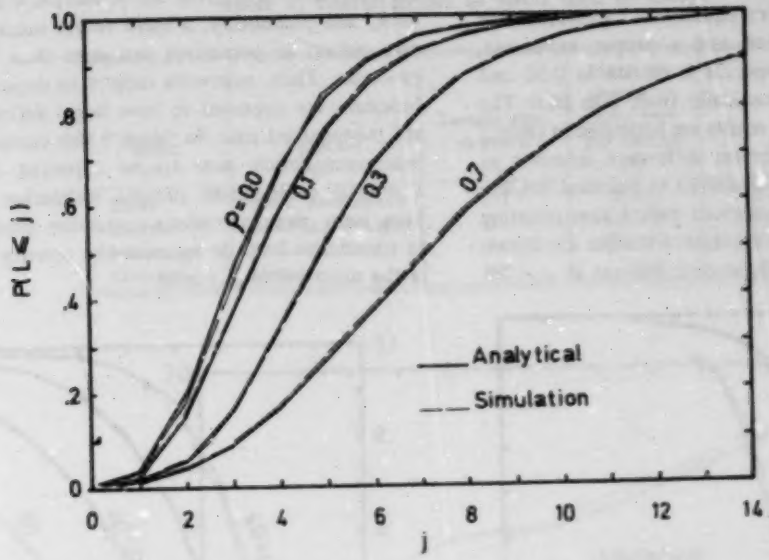

Figure 6. Cumulative pdf of longest drought duration for $n = 25$, and various correlation coefficients

$$\mu_D = \frac{\exp\left(\frac{-x_0^2}{2.0}\right)}{p}(2\pi)^{1/2} + x_0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (14)$$

$$\text{and} \quad \sigma_D^2 = 1 + x_0\frac{\exp\left(\frac{-x_0^2}{2}\right)}{p}(2\pi)^{1/2} - \frac{\exp(-x_0^2)}{2}\pi p^2 \quad \ldots\ldots\ldots \quad (15)$$

Mean μ_s and variance σ_s^2 of deficit sum corresponding to a drought duration of length i can be evaluated through

$$\mu_s = i\mu_D \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (16)$$

and approximately

$$\sigma_s^2 = \sigma_D^2\left\{i + 2\rho\frac{i(1-\rho) - (1-\rho^i)}{(1-\rho)^2}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (17)$$

respectively. With these parameters the approximate form of deficit sum pdf can be written as

$$P\{D \le s\} = \sigma_s^{-1}(2\pi)^{-1/2}\int_0^s \frac{\exp\left[-(D-\mu_s)^2\right]}{2}\sigma_s^2 dD \quad \ldots\ldots\ldots \quad (18)$$

Table 2. Expected value of maximum deficit sum

	TRUNCATION LEVEL $q = 0.5$											
	$\rho = 0.0$			$\rho = 0.1$			$\rho = 0.2$			$\rho = 0.3$		
Sample length, n (1)	Analytical (2)	Simulation (3)	Difference (4)	Analytical (5)	Simulation (6)	Difference (7)	Analytical (8)	Simulation (9)	Difference (10)	Analytical (11)	Simulation (12)	Difference (13)
25	3.61	3.60	0.01	3.81	3.90	−0.09	4.17	4.22	−0.04	4.50	4.60	−0.10
50	4.58	4.55	0.03	4.87	5.01	−0.14	5.42	5.50	−0.08	5.90	6.08	−0.18
100	5.50	5.55	−0.05	5.91	6.15	−0.24	6.70	6.85	−0.15	7.50	7.70	−0.20
200	6.42	6.41	0.01	6.95	7.03	−0.08	7.95	7.95	0.00	6.80	8.99	−0.19
500	7.65	7.56	0.09	8.41	8.64	−0.23	9.63	9.73	−0.10	10.80	11.00	−0.20

The cumulative pdf of maximum deficit sum can be numerically evaluated from equation 12 provided that equation 18 is substituted and a proper increment, Δs is adopted. In this paper Δs is chosen as 0.50 and s is allowed to change practically from 0 to 20.0. The numerical and simulation results are presented in table 2 where the absolute maximum difference amounts to 0.24, which can be easily neglected in practical studies. The cumulative pdf of maximum deficit sum resulting both from analytical and simulation studies are shown in figure 7 for normal independent process at $q = 0.5$

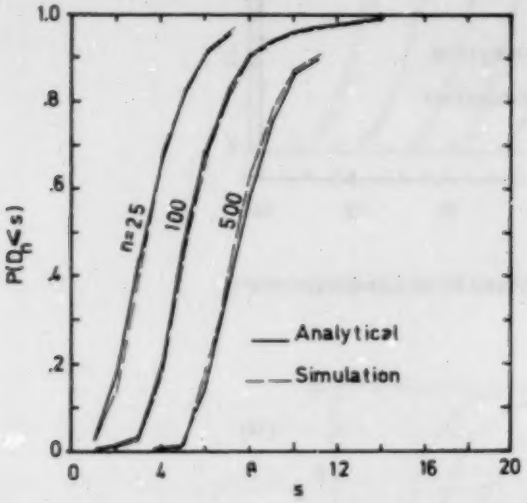

Figure 7. Cumulative pdf of maximum deficit sum for $q = 0.5$, $\rho = 0.0$, and various sample sizes

truncation level. The agreement between the two approaches seems to be very good, which also confirms the validity of normal pdf assumption for deficit sums as a satisfactory approximation in equation 18. The cumulative pdf of maximum deficit sum in persistent processes has been examplified for $\rho = 0.3$ at $q = 0.5$ in figure 8. Comparison of figure 7 with figure 8 reveals

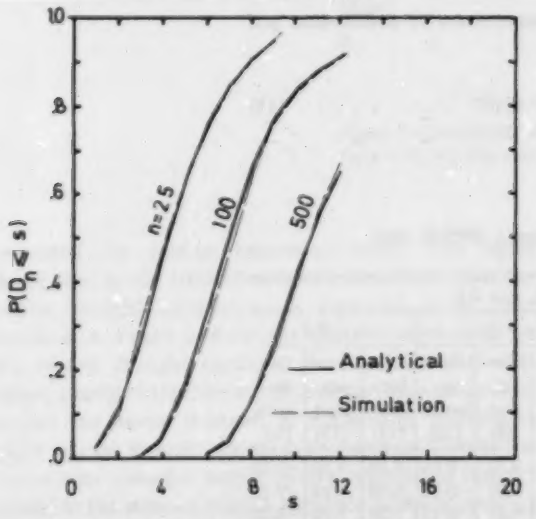

Figure 8. Cumulative pdf of maximum deficit sum for $q = 0.5$ and $\rho = 0.3$

the fact that for a given set of sample size, truncation level, and probability, a more severe maximum deficit sum occurs in persisitent processes than independent processes. Thus, reservoirs subject to dependent inflow processes are expected to have larger deficit sums than the independent case. In figure 9 this cumulative pdf of maximum deficit sum to be expected to occur in a normal independent process realization of size 25 have been given at various truncation levels. Increases in truncation level do increase the severity of drought at the same probability level.

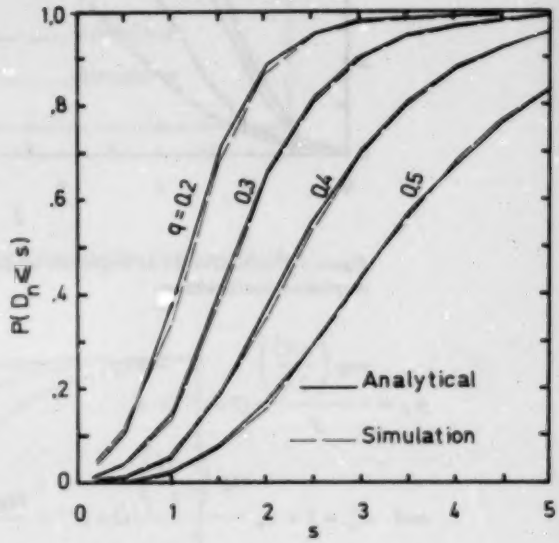

Figure 9. Cumulative pdf of maximum deficit sum for $n = 25$, $\rho = 0.0$, and various truncation levels

Applications

The applications of the methodology developed herein were performed for four annual streamflow records observed at various parts of the world. The characteristics of these records are presented in table 3. The original records are available in another Yevjevich reference[9] in modular coefficients form that are simply the ratio of annual flows to the mean annual flow; therefore, they are dimensionless.

Figure 10 shows both the historical and experimental upcrossings number for the Rhine River at Basle, Switzerland. The agreement seems to be very good at least for large sample sizes. In figures 11-14 the longest drought durations obtained from historic records at modular truncation levels $x_o = 0.0$ to 2.0 are connected with broken lines whereas solid lines corresponding to the analytical expected value of the longest drought duration are obtained through the numerical solution of equation 9 with the convenient

9 V. Yevjevich, "Fluctuations of wet and dry years", *Hydrology Paper 1*, Colorado State University (Fort Collins, Colorado, 1963).

Table 3. Characteristics of rivers used in study

River (1)	Location (2)	Sample size, in years (3)	Mean discharge, in cubic feet per second (4)	ρ (5)
Rhine	Basle, Switzerland	150	36,253	0.077
Danube	Orshova, Romania	120	189,455	0.096
Mississippi	St. Louis, Mo.	96	175,119	0.294
Missouri	Montana	65	7,635	0.593

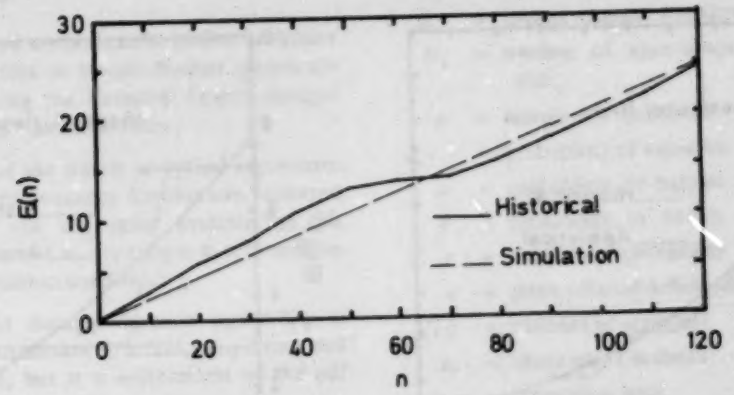

Figure 10. Number of upcrossings for Rhine River at Basle, Switzerland

parameters presented in table 3. In general, historical and analytical expectations of the longest drought durations agree closely with each other. The deviations of historical values from the analytical counterparts are due to mainly two reasons: (i) Sampling variability of historical longest drought durations in finite sample sizes, only a single sample can be obtained from the population of the longest drought durations for a given sample size, truncation level, and time series structure considered; and (ii) the single sample obtained from historic record has an integer value whereas the theoretical average longest drought duration is not necessarily an integer number. On the other hand, the agreements between historical and analytical values in figures 11-14 show that for these four rivers taken as examples, the simple lag-one Markov process not only reproduces

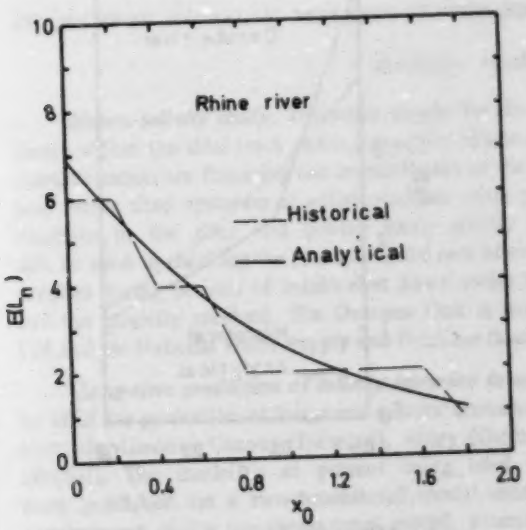

Figure 11. Expected value of longest drought duration for Rhine River

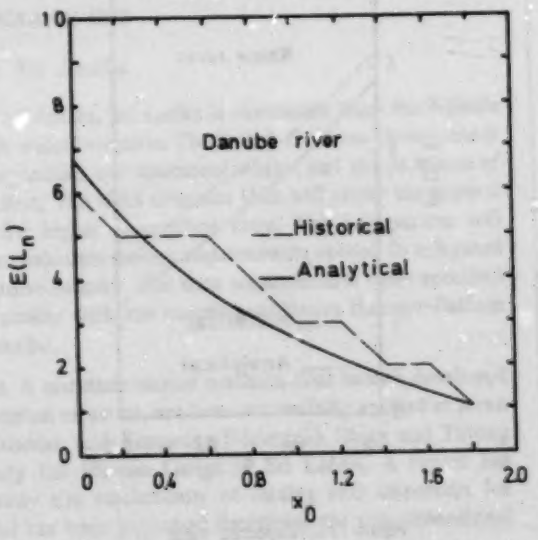

Figure 12. Expected value of longest drought duration for Danube River

the longest historical drought duration but also yields larger synthetic drought durations for the same sample size than the historical droughts.

In figures 15 and 16 historical and analytical expected values of the maximum deficit sum at various truncation levels are given for Rhine and Danube Rivers. For the Rhine River, where $\rho = 0.077$, the historical droughts at all the truncation levels are always greater than the theoretical counterparts, i.e., the simple lag-one Markov process cannot reproduce the average maximum deficit sum in the same sample size, but it rather underestimates the maximum deficit sum. Furthermore, since, generally, in many water-resources projects, such as reservoir design, the maximum deficit sum is employed as the main indicator of the critical drought; therefore the simple lag-one Markov process must not be employed as a suitable model for the Rhine River. The same argument is also valid for the Danube River where at most of the truncation levels historical drought severity is smaller than the analytical one.

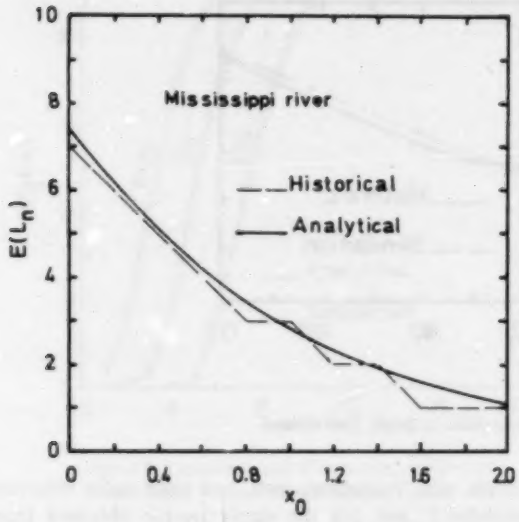

Figure 13. Expected value of longest drought duration for Mississippi River

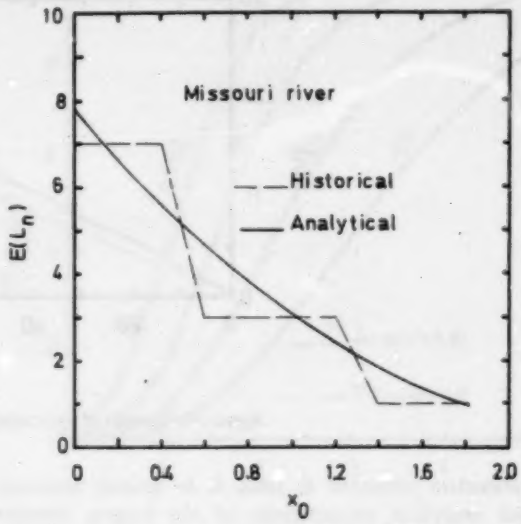

Figure 14. Expected value of longest drought duration for Missouri River

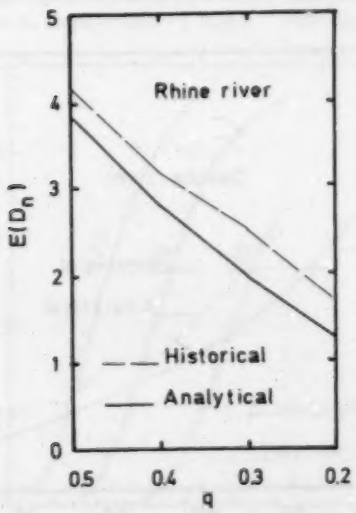

Figure 15. Expected value of maximum deficit sum for Rhine River

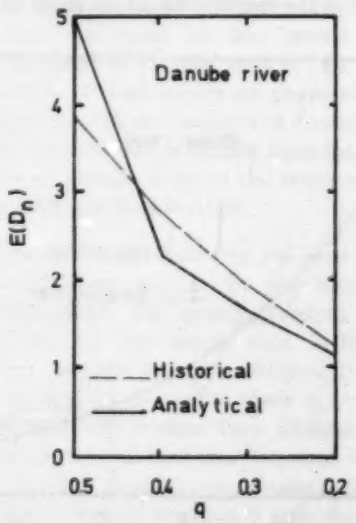

Figure 16. Expected value of maximum deficit sum for Danube River

Conclusions

The critical drought, either in the form of longest drought duration or maximum deficit sum, has been analytically investigated on the basis of random number of random variables. The pdf of both longest drought duration and maximum deficit to be expected in a finite sample length at various truncation levels have been derived for independent and lag-one Markov processes. The application of the methodology presented herein has been performed for observed annual flow sequences. The following important conclusions can be drawn from this study:

1. The presented method can be used to determine whether an independent or lag-one Markov process are capable of reproducing the historical longest drought duration and the maximum deficit sum.

2. By means of the simple analytical expressions for the critical drought frequency distributions presented in the main text, one can easily evaluate the risk associated with a drought in any sample size, truncation level, and serial correlation coefficient.

3. The longest drought duration probability is dependent on the correlation structure, sample size, and the truncation level, but it is independent of the pdf of underlying flows.

4. Although the lag-one Markov processes are capable of reproducing the mean, standard deviation, lag-one serial correlation coefficient, and drought durations, they do not preserve deficit sums.

5. The analytical formulation given in this paper makes it possible to find the probabilistic and statistical properties of droughts without resorting to computer simulations, which are cumbersome and expensive.

Annex

NOTATION

The following symbols are used in this paper.

$E(\cdot)$ = expectation of argument
E_i^n = event of i droughts in sample of size n
D_j = drought severity (deficit sum)
D_n = maximum deficit sum in sample of size n
k = random number of droughts
L_j = drought duration
L_n = longest drought duration in sample of size n
N_i = number of upcrossings within sample of size i
n = sample size considered
$P \cdot$ = probability of argument
p = probability of surplus at any time instant
q = probability of deficit at any time instant
r = conditional probability
s = given value of deficit sum
$V(\cdot)$ = variance of argument
x_i = observation at time i
x_o = truncation level
μ_D = expected value of deficits at x_o level
μ_s = expected value of deficit sum
p = first-order serial correlation coefficient
σ_D^2 = variance of deficits at x_o level
σ_s^2 = variance of deficit sum
ϕ = empty set
Ω = universal set

REPORT FROM HYDRAULIC RESEARCH STATION (HRS), ENGLAND, 1981

Salinity studies in Sri Lanka

Matara salinity study. The water supply for the town of Matara, Sri Lanka is abstracted from the Nilwala Ganga within the tidal reach and is frequently affected by salt water intrusion. The British Overseas Development Administration are financing the improvement of the existing intake and treatment works, and the provision of new works sited upstream of anticipated salt water penetration. The HRS Overseas Unit will study the present situation in the river and predict likely salinity levels for higher abstraction rates. The information will also be used in checking the location of the new intake and to calculate storage requirements needed to safeguard supplies during periods of intake shut down owing to excessive salinity. The data required have been specified and the majority received. The Overseas Unit is working closely with the consultants Messrs Halcrow-Balfour Ltd and the National Water Supply and Drainage Board, Colombo.

Long-term prediction of salinity intrusion in estuaries. A one-dimensional mathematical model, developed by HRS for prediction of long-term salinity intrusion in tropical estuaries, has been successfully applied at seven sites: the Gambia, Guayas (Ecuador), Abary (Guyana), Kuantan and Kemaman (Malaysia), Belait and Tutong (Brunei). The model is at present being used to study the Nilwala Ganga in Sri Lanka. A report has been published on a two-dimensional model used to study the mechanisms of mixing and dispersion for development of the one-dimensional model. A user manual has been published describing the one-dimensional model, the computer programme and how the model may be applied.

TECHNICAL APPLICATIONS

COMPUTER PROGRAMME FOR A RIVER HYDRO DEVELOPMENT

*N. Murray and K. Weissbeck**

A model is described for application at the prefeasibility and feasibility study stages of a hydropower development in a river basin, it evaluates and optimizes the main dimensions and operating characteristics of alternative development schemes involving the phased construction of a number of hydropower sites in series. The optimization criterion used is the maximization of net benefits. The use of generalized reservoir "yield" curves allows the long-term development to be evaluated with economic use of computer time.

In the article "Selection of optimum reservoir volume and installed capacity for hydro stations" published in *Water Power & Dam Construction*, June 1975, Messrs. Inderbitzin, Laver and Weissbeck describe a procedure for determining optimum reservoir height, storage volume and installed capacity of hydro stations that are to operate in a mixed hydro-thermal generating system, and whose main features (e.g. dam site, tunnel alignment, power station site) are already known.

Many cases, however, require the evaluation of the hydropower potential of the whole or part of a river or river system where specific projects have not yet been identified. The need was thus felt for a "screening" procedure by which a number of possible schemes could be identified quickly, evaluated and ranked in order of economic merit as a first stage in project selection.

The computer-based evaluation model described in this article was therefore developed by the authors to assist in satisfying this need. The model is designed to carry out the evaluation and optimization of the hydropower development of a river basin where various hydropower plants in series are envisaged as a long-term development programme, and where several possible development schemes can be identified.

The procedure is divided into two stages. In the first stage, preliminary engineering desk and field studies identify all the sites and design features of basic components (such as dams, pressure tunnels, power stations) which may be combined in various ways to make up the possible schemes. These engineering studies cover the preparation of preliminary designs and cost estimates of the project components, each for a range of sizes.

In the second stage, all the feasible development programmes are evaluated and optimized within the context of the regional or national interconnected electricity supply system and the best scheme over-all is identified. The basic objective is to find the development programme which will produce the maximum net economic benefits over the life of the scheme. It is in this second stage that the computer model described in this article is applied to identify the optimum scheme rapidly.

The model is structured in the classical dynamic programming form in which a set of recursive relationships are successively solved for a set of "state" parameters at each of a set of "stages". In this case the recursive relationships are the equations for head, storage volume, discharge, power, energy costs, benefits and other factors which are the state variables. The stages are the successive hydropower sites along the river, which together comprise an over-all development scheme.

The model carries out the full optimization and evaluation procedure of each development option in a single run, irrespective of the number of sites. An interesting feature of the programming of the model is that the runs are carried out interactively, with the characteristics of the selected sites being displayed on a video screen. This allows the engineer to test during the run, the sensitivity of the evaluation result to variations of any of a number of parameters such as the dead storage volume at a particular reservoir.

Selection of possible schemes

A typical case for which the model is designed is illustrated in figure 1, which shows a hypothetical situation where a prefeasibility study for the hydropower development of a river reach is to be carried out.

It is supposed that desk studies and field reconnaissance missions have identified three possible dam sites, 1, 2 and 3, and four possible power station locations, a, b, c and d (of which a and d are underground, and b and c are on the surface). The longitudinal profile shows the elevation of the various dam, tunnel and power station sites, and the upper limits for the top water levels of the reservoirs corresponding to each

* Electrowatt Engineering Services (London) Ltd, United Kingdom; and Electrowatt Engineering Services (Zurich) Ltd, Zurich, Switzerland; respectively. This article was originally published in *Water Power & Dam Construction* (ISSN 0306-400X; vol. 32 No. 3, March 1980), and is reprinted here with permission from the publishers. Copyright 1980 by IPC Business Press Ltd.

Table 1. Development options*

Scheme	Dam site 1	2	3
1	—	—	3-d
2	—	2-c	—
3	—	2-c	3-d
4	—	2-d	—
5	1-a	—	—
6	1-a	—	3-d
7	1-a	2-c	—
8	1-a	2-c	3-d
9	1-a	2-d	—
10	1-b	—	—
11**	1-b	—	3-d
12	1-b	2-c	—
13**	1-b	2-c	3-d
14**	1-b	2-d	—
15	1-c	—	—
16**	1-c	—	3-d
17**	1-d	—	—

Notes: * See Figures 1 and 2.
** Schemes which can utilize the full potential head of the river reach.

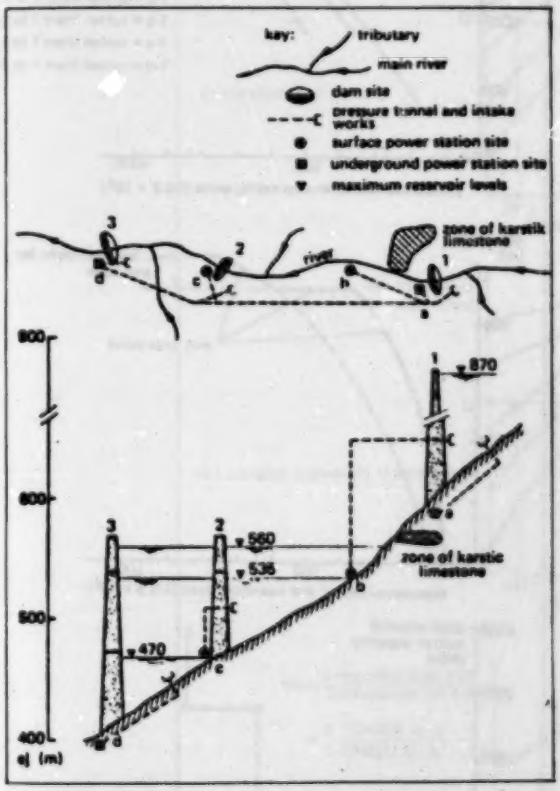

Figure 1. Dam sites (1, 2 and 3), power stations (a, b, c and d) and tunnels identified by preliminary engineering studies.

of the upstream power station sites. In this example it is further supposed that a zone of karstic limestone on the right bank of the river between sites a and b presents an upper limit of elevation 560 m, for the two lower reservoirs, forming an additional constraint for the height of dams 2 and 3. It is emphasized that the top water levels shown are maxima, not necessarily to optimal–this is for the model to determine.

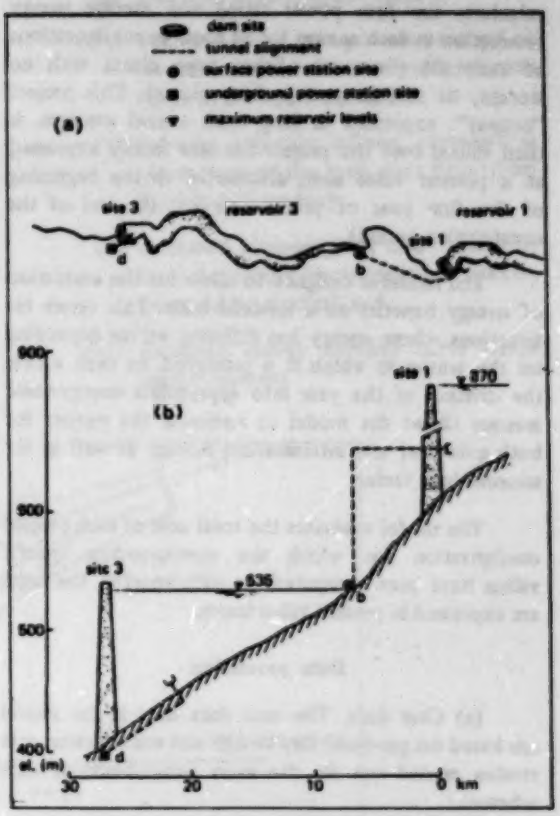

Figure 2. (a) Plan, and (b) longitudinal profile of typical scheme No. 11 (see table 1).

Table 1 lists the possible ways in which the various components may be combined to give 17 technically feasible development schemes. Figure 2 illustrates a typical individual scheme, No. 11, comprising two reservoir sites.

Economic criteria for evaluation and optimization

There are various commonly used indices by which various development options may be optimized and compared economically, such as net benefits, benefit-cost ratio or internal rate of return.

Any or all of these indices can be computed using the model described. In the form discussed in this paper the model uses the maximization of net benefits as the ruling criterion both for scheme optimization and ranking of the optimized schemes.

The model is designed to evaluate and optimize projects which are essentially single-purpose for hydropower only. While the regulation effect of the reservoir might produce other benefits (or disadvantages) in particular cases, these are not directly computed by the model in its present form.

The approach adopted is to assign unit values to energy and firm power which reflect their long-term marginal cost to the interconnected system. The model

calculates the firm power rating and average energy production in each season for all possible configurations of each site (from run-of-river type plants with no storage, to storage-type peaking plants). This project "output", expressed as long term annual averages, is then valued over the project life and finally expressed as a present value sum, discounted to the beginning of the first year of production (i.e, the end of the construction period).

The model is designed to allow for the evaluation of energy benefits on a seasonal basis. This caters for situations where energy has differing values depending on the season in which it is produced. In such a case the division of the year into appropriate energy-value seasons allows the model to optimize the project for both over-year and interseasonal storage as well as for seasonal load factor.

The model evaluates the total cost of each project configuration for which the corresponding benefit values have been computed. As with benefits, the costs are expressed in present value terms.

Data processing

(a) *Cost data.* The cost data used in the model are based on pre-feasibility design and construction cost studies carried out for the main components of each scheme.

Construction programmes are prepared for each component and the corresponding sets of cash flows of capital and operating costs are derived and discounted at various rates of interest, *i*.

The resulting discounted costs comprise the basic input cost data for the computer model, in the form of curves versus an appropriate design parameter. The parameters used are:

Cost items:	*Cost/design parameter:*
dams and appurtenant works (diversion tunnel, spillway, bottom outlet, etc)	dam height (m)
tunnels and power stations (including all plant)	installed capacity (MW)
transmission lines.	installed capacity (MW)

Typical examples of these composite, discounted cost curves (for site 1 of the example case) are shown in figure 3. The upper drawing refers to tunnels each curve includes the cost of the respective power station as a function of installed turbine capacity.

At site 1 it is supposed that two dam types are considered: arch and rockfill. The arch dam is shown to be the cheaper structure for heights up to 235 m, but poor geological conditions in the abutments above this level rule out arch dams for anything higher (figure 3 b).

The transmission cost curve (figure 3 c) typically takes a stepped form, indicating that additional lines must be introduced at specific values of power capacity as the total line capacity increases.

The discontinuities which occur in the cost curves 3 b and c present no problem to the model, but are of course reflected in the evaluation and optimization results. Similar sets of cost curves are developed for sites 2 and 3.

(b) *Hydrological data.* The basic hydrological data required are the monthly historical streamflows at each

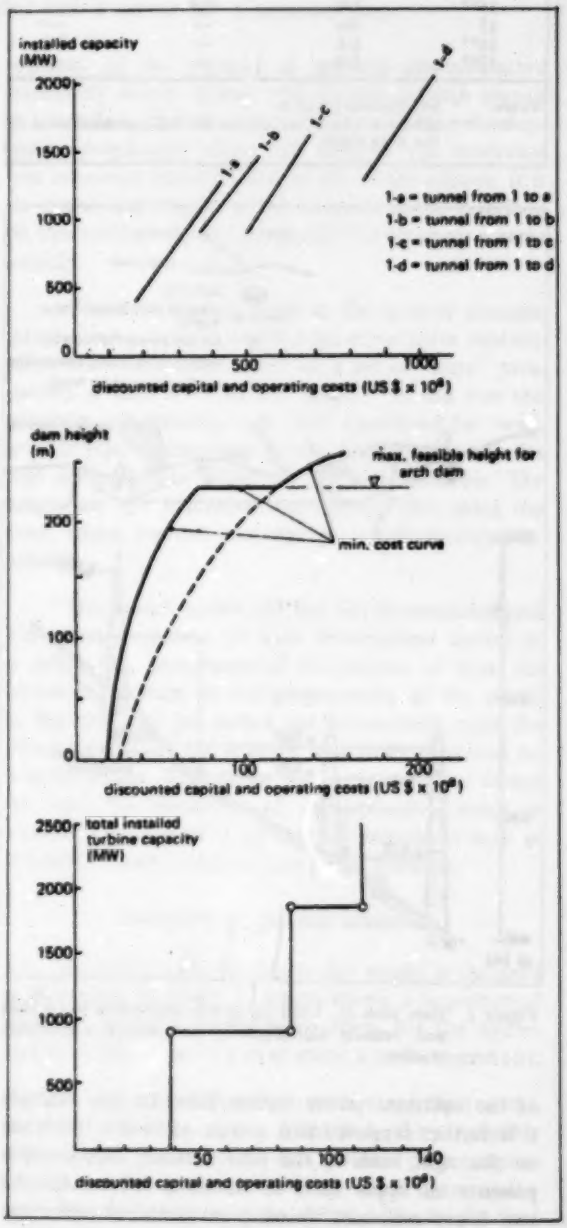

Figure 3. Discounted cost curves for site No. 1. Curves apply to (a) tunnels and power stations; (b) dams and appurtenant structures; and, (c) transmission line costs

dam site. If such river flow data are not directly available from gauging station records or are of insufficient quality or duration, then synthetic data must be provided by an appropriate hydrological technique (not discussed here).

The basic stream flow data are used by the model to derive reservoir yield functions, as discussed further on.

(c) *Other data.* Other items of basic data which must be provided to the computer as input are the following:

(a) Reservoir height-volume curves;

(b) Minimum dead storage volume required for sediment-retention at each reservoir (from hydrological studies);

(c) inter-site tributary inflows, expressed as percentages of the main river flow (from hydrological studies);

(d) estimated time-weighted mean head loss in each pressure tunnel/penstock system, (from design studies); and,

(e) projected energy demand curve (from market studies).

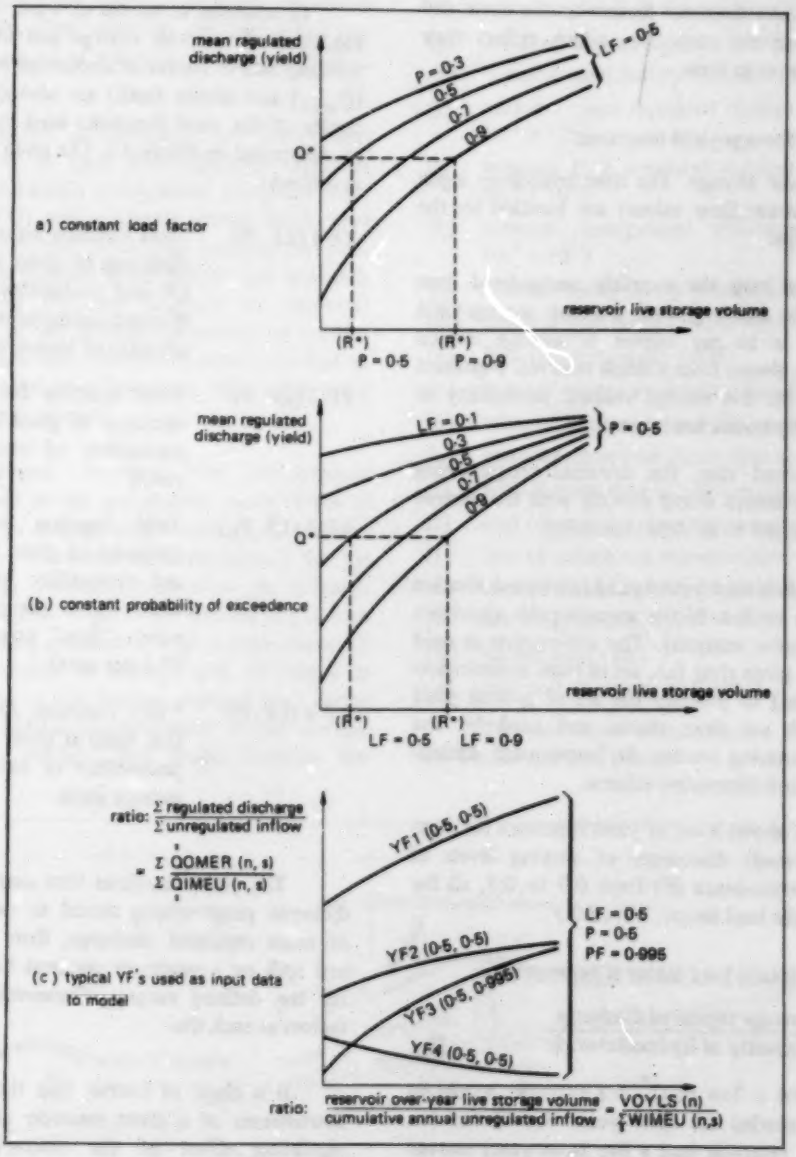

Figure 4. Reservoir yield functions, showing: (a) constant load factor; (b) constant probability of exceedance; and, (c) typical yield functions used as input data to the model.

Demand growth and project phasing

The criterion used in the model to determine the phasing intervals between the construction of the various sites is that the firm energy output should satisfy the projected increase in annual average energy demand throughout the development period. Thus for each scheme the construction intervals are determined by two factors: (a) the firm energy output at each site; and (b) the projected growth in annual system energy demand.

The former is computed during the evaluation process and the latter is provided as input data based on power market studies.

The model allows for phasing of the projects by applying appropriate discount factors to the costs and benefits calculated for each site, which reflect their relative displacement in time.

Storage-yield functions

(a) *Over-year storage*. The river hydrology input data (monthly streamflow values) are handled by the model in two steps.

In the first step the monthly unregulated river flows are used to derive general reservoir storage-yield functions; that is to say curves of average annual regulated water releases from a single reservoir expressed as functions of the live storage volume, probability of exceedence and hydraulic load factor.

In the second step, the dynamic programming optimization procedure works directly with the derived yield curves (referred to as yield functions).

The procedure used by the yield function derivation sub-routine is a version of the sequent-peak algorithm (residual mass-curve analysis). The sub-routine is used only once for a given river (i.e, set of basic hydrological stream flow data) to produce the set of general yield functions which are then stored and used by the dynamic programming routine for subsequent optimization runs on each alternative scheme.

Figure 4 a shows a set of yield functions for regulated (i.e, turbined) discharges of varying levels of probability of exceedence (P) from 0.9 to 0.3, all for constant hydraulic load factor, LF, of 0.5.

Where hydraulic load factor is expressed as:

$$LF = \frac{\text{Average regulated discharge}}{\text{Capacity of hydraulic works}}$$

In this case a flow of Q^*, for example, would be equalled or exceeded for nine years out of ten (on average) if the reservoir had a live (over-year) storage capacity of $(R^*)_{P=0.9}$, and the hydraulic works a maximum discharge capacity, Q_{max} of $2Q^*$. Alternatively the same regulated discharge Q^* could be maintained for five years out of ten (on average) with a (smaller) regulation storage of $(R^*)_{P=0.5}$.

Figure 4 b shows a set of yield functions, this time for a range of load factors, but with a constant probability level of 0.5. In this case a regulated discharge of Q^* can be achieved for five years out of ten either with a reservoir storage volume of $(R^*)_{LF=0.5}$ together with a maximum discharge capacity of $Q_{max} = 2\,Q^*$ (the latter case discussed above), or with a larger reservoir storage of $(R^*)_{LF=0.9}$ and a maximum hydraulic capacity of:

$$Q_{max} = Q^*/0.9 = 1.11\,Q^* \text{ (load factor = 0.9)}$$

In addition to curves of mean yield expressed as functions of reservoir storage and load factor, corresponding sets of curves of maximum regulated discharge (Q_{max}) and excess (spill) are also derived. A typical family of the yield functions used in the optimization are illustrated in Figure 4 c. The given curves are defined as follows:

YF 1 (LF, P): Yield function for *maximum* regulated discharge of given average load factor LF and probability of exceedence P. (Corresponding to maximum hydraulic capacity of tunnel/turbines system)

YF 2 (LF, P): Yield function for *average* regulated discharge of given load factor LF and probability of exceedence P. (Basic yield)

YF 3 (LF, P_F): Yield function for *firm* regulated discharge of given load average factor and probability of exceedence, P_F, where P_F is the probability level at which "firm" power is defined (e.g, 99.5 per cent)

YF 4 (LF, P): Yield function for *excess* discharge (i.e, spill) at given load factor LF and probability of exceedence, P of the *average* yield.

The yield functions thus derived are used in the dynamic programming model to determine the values of mean regulated discharge, firm regulated discharge and spill on a yearly or seasonal basis, as appropriate, for the defined ranges of reservoir volume and load factors at each site.

It is clear, of course, that the inflows to all sites downstream of a given reservoir are modified by the regulating effect of the reservoir. The additional regulating effects of the downstream reservoir(s) cannot be obtained simply by applying the yield functions to the total inflows directly. This problem is overcome by

expressing the volume-regulation functions in terms of the following ratios:

$$x = \frac{\text{reservoir live storage volume (VLS)}}{\text{cumulative annual mean unregulated inflow (QIMEU)}}$$

$$y = \frac{\text{cumulative annual mean regulated discharge (VLS)}}{\text{cumulative annual mean unregulated inflow (QIMEU)}}$$

These ratios are used respectively as the x and y co-ordinates *of* the yield functions, as shown in Figure 4 c. The functions may then be applied to all successive reservoirs provided they operate only on the residual unregulated component of inflow for each reservoir (the sum of the unregulated spill from the reservoir immediately upstream and the lateral tributary unregulated inflows between the upstream and the considered reservoir). For the first reservoir of the series this unregulated component of inflow is, of course, equal to the total inflow.

Figure 5 shows schematically the three components of inflow at each site: regulated discharge from upstream (QIMER), unregulated discharge from upstream (QOMEU) and upstream lateral (tributary) inflow (G. QIMEU); the latter two forming the total unregulated inflow (QIMEU). Implicit in this approach is the assumption that the monthly (or seasonal) discharge pattern of the residual component of unregulated inflow at each site, QIMEU, is similar to that of the total unregulated riverflow from which the yield functions are initially derived.

(b) *Interseasonal storage.* The storage-yield functions discussed so far are derived on the basis of a constant yield, or average rate of release, throughout the year. It may, however, be advantageous for the purposes of energy production, to allow for different rates of average release in different seasons (e.g, a high rate of release during a season of high energy demand). This seasonal variation in average rate of release is expressed in terms of the average seasonal load factor and requires an additional component of live storage; interseasonal live storage. The model includes the facility to optimize the reservoir live storage volume separately with respect to over-year and interseasonal components of live storage.

Optimization procedure

The model is designed to find the optimum dimensions of each component of schemes of the type listed in table 1, and to print out the following characteristics (state variables):

(a) reservoir dead storage volume ($m^3 \times 10^6$)
(b) reservoir over-year storage volume ($m^3 \times 10^6$)
(c) reservoir interseasonal storage volume ($m^3 \times 10^6$)
(d) maximum head on the turbines (m)
(e) seasonal mean head on the turbines (m)
(f) minimum head on the turbines (m)
(g) installed turbine capacity (MW)
(h) seasonal mean inflow volume ($m^3 \times 10^6$)
(i) seasonal mean regulated turbine discharge volume ($m^3 \times 10^6$)
(j) seasonal firm regulated turbine discharge volume ($m^3 \times 10^6$)
(k) seasonal unregulated discharge (spill) volume ($m^3 \times 10^6$)
(l) seasonal mean energy production (GWh)
(m) seasonal firm energy production (GWh)
(n) firm power capacity (MW)
(o) value of energy production benefit ($US $\times 10^6$)
(p) value of firm power production benefit ($US $\times 10^6$)
(q) seasonal mean load factor (per cent)
(r) annual mean load factor (per cent)
(s) cost of dam and appurtenant structures ($US $\times 10^6$)
(t) cost of tunnel and power station ($US $\times 10^6$)
(u) cost of transmission lines ($US $\times 10^6$)
(v) net benefits ($US $\times 10^6$)
(w) benefit/cost ratio
(x) unit cost of energy (mil/kWh)

The last three characteristics are also computed for the scheme as a whole.

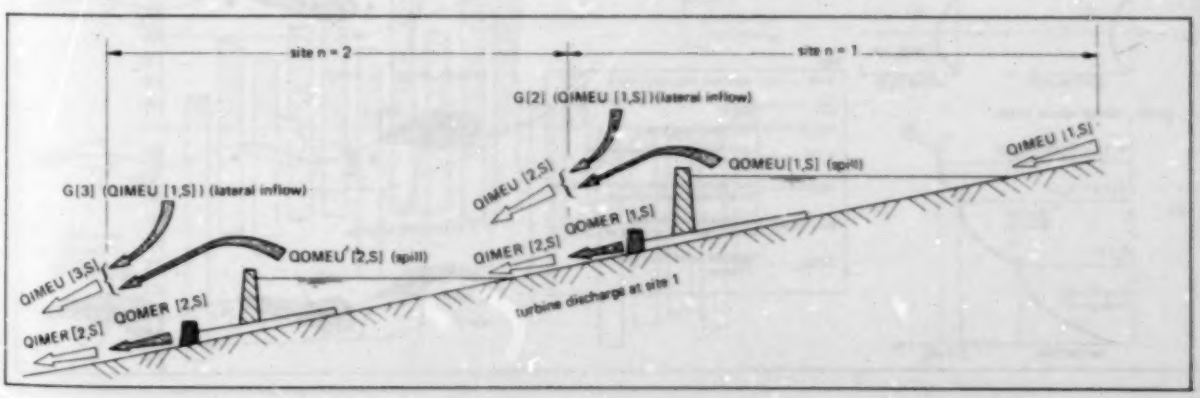

Figure 5. Profile along the river to show the flow and continuity functions – –definition of terms.

The recursive optimization procedure moves from upstream to downstream and is illustrated schematically in figure 6 for a typical three-site scheme, e.g. No. 8 in table 1. The key variable at each site is reservoir volume, V, (being the sum of over-year, interseason and dead storage). The functions are first satisfied for a set of combinations of live and dead storage at reservoir No. 1 only, including the case of zero storage (i.e. no dam), and with no dams at sites 2 and 3, (i.e. these sites are initially taken as run-of-river plants). The results are expressed as the net benefits for each site, NB (1, 1) NB (2, 1) NB (3, 1), generated as a result of the river regulation effect of the reservoir volume V (1) at site 1 only, as shown in figure 6 a. The net benefits at each power station are computed for a range of seasonal load factors (i.e. installed turbine capacities), and the optimum solution for stage 1 is that combination of live and dead storage volumes at reservoir 1 and seasonal load factors at power stations a, b and c, which produces the maximum total of net benefits at sites 1, 2 and 3, i.e:

$$\text{Maximum } [NB(1, 1) + NB(2, 1) + NB(3, 1)],$$

which is the maximum point of the left hand curve in figure 6 a, being the sum of curves (1), (2) and (3).

Having found the optimum state for site 1, i.e. the best height of the dam and installed turbine capacity, the programme next moves to reservoir site 2 and repeats the procedure. The optimum state for site 2 is now given by the total reservoir volume at site 2, $V(2)$, which produces the maximum sum of additional net benefits at sites 2 and 3 caused by the reservoir at site 2 (curves (4) and (5) in figure 6 b).

This procedure is repeated for reservoir site 3 in the same way. An indefinite number of sites may be treated in this manner.

This optimization procedure is applied in turn to each of the possible schemes listed in table 1. Finally these optimized schemes are compared to find the over-all best scheme.

Objective and constraint functions

The set of recursive functions which the model must satisfy at each stage of the evaluation/optimization procedure may be classified as:

(a) objective functions (of which there are six); and,
(b) constraint functions (of which there are 33).

The objective functions are those which express the result of the evaluation/optimization procedure, e.g. expressions for net benefits, benefit-cost ratio and unit cost of energy.

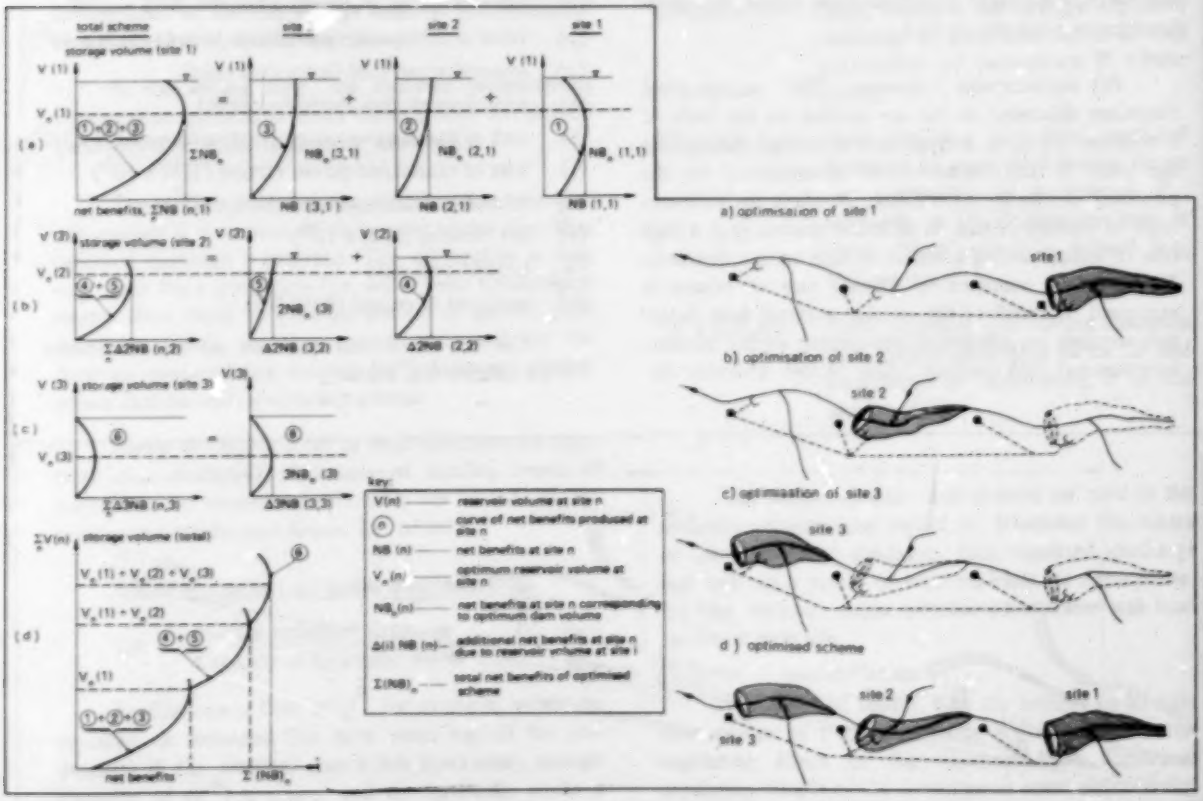

Figure 6. Economic optimization procedure for a typical three-site scheme (e.g. No. 8 in table).

The "constraint" functions are the equations and limits which must be satisfied at each stage during the evaluation procedure, and which give the values of the state variables, i.e. live and dead storage, seasonal energy, firm and average power, among other factors. For convenience the "constraint" functions are further divided into four groups:

2.1 Reservoir volume (figure 7): six functions;

2.2 Head (figure 7): twelve functions;

2.3 Flow and continuity (figure 5): five functions; and,

2.4 Power and energy: ten functions.

The complete set of functions is given in table 2. The terms used in the functions are defined in table 3 and illustrated in figures 5 and 7.

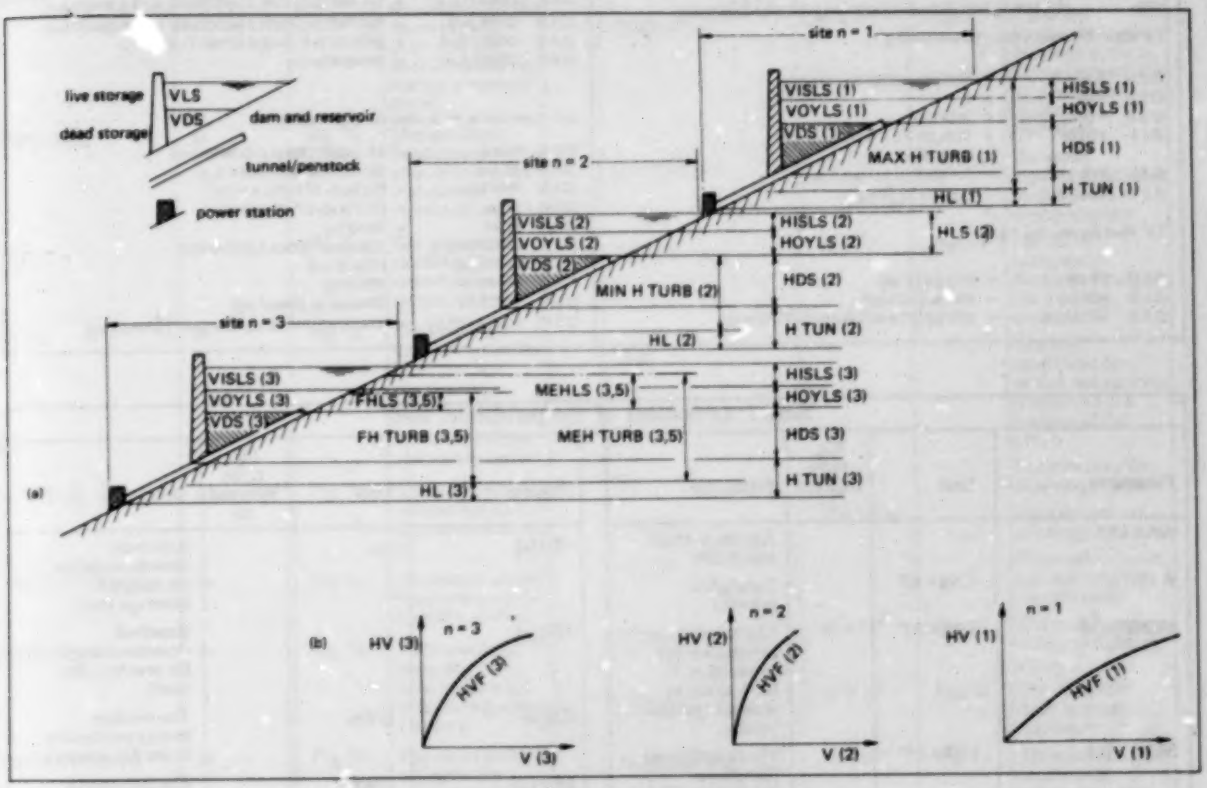

Figure 7. Reservoir storage volume and head functions: definition of terms, showing: (a) longitudinal profile through the reservoirs, and (b) reservoir height/volume functions HVF(n).

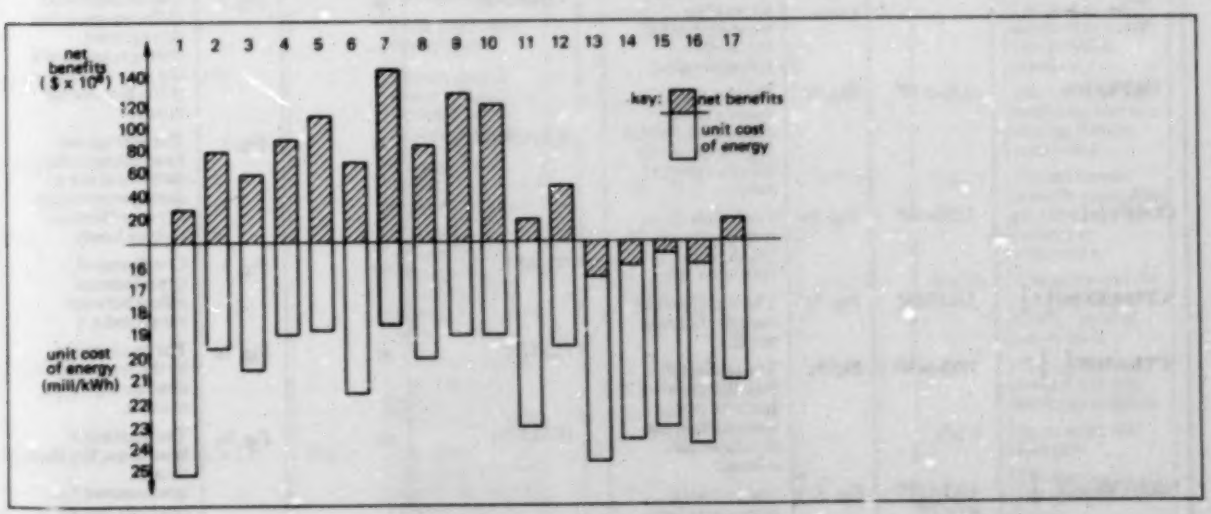

Figure 8. Results of comparative economic evaluation.

Table 2. Recursive relationships

2.1 *Objective functions*

(2.1.1) Net benefits, per site
NB [n] = PVF [n] (ΣBENE [n,s] + BENFP [n] − COSTV [n] − COSTP [n]) − COSTRANS [n]
(2.1.2) Total net benefits
NB = Σ NB [n]
(2.1.3) Benefit/cost ratio, per site
B/C [n] = (ΣBENE [n,s] + BENFP [n]) / (COSTV [n] + COSTP [n] + COSTRANS [n])
(2.1.4) Benefit/cost ratio for the whole scheme
B/C = (Σ(ΣBENE [n,s] + BENFP [n])) / (Σ(COSTV [n] + COSTP [n] + COSTRANS [n]))
(2.1.5) Unit cost of energy, per site
UCE [n] = (COSTV [n] + COSTP [n] + COSTRANS [n]) / (UCEF ΣE [n,s])
(2.1.6) Unit cost of energy for the whole scheme
UCE = (Σ(COSTV [n] + COSTP [n] + COSTRANS [n])) / (UCEF Σ(ΣE [n,s]))

2.2 *Reservoir storage volume functions* (See Fig. 7)

(2.2.1) V [n] = VDS [n] + VOYLS [n] + VISLS [n]
(2.2.2) V [n] ≥ 0
(2.2.3) V [n] ≤ VMAX [n]
(2.2.4) VDS [n] ≥ VDSMIN [n], if V [n] > 0
= 0, if V [n] = 0
(2.2.5) VISLS [n] = (1 − X[s]) S[s] Σ QOMER [n,s]
(2.2.6) COST V [n] = COSTVF [n] [V [n]]

2.3 *Head functions* (See Fig. 7)

(2.3.1) HV [n] = HVF [n] [V [n]]
(2.3.2) HDS [n] = HVF [n] [VDS [n]]
(2.3.3) HOYLS [n] = HVF [n] [VDS [n] + VOYLS [n]] − HDS [n]
(2.3.4) HISLS [n] = HV [n] − HDS [n] − HOYLS [n]
(2.3.5) HLS [n] = HOYLS [n] + HISLS [n]
(2.3.6) HLS [n] ≤ 0.3 (HV [n] + HTUN [n] − HL [n])
(2.3.7) MEHLS [n,s] = HVF [n] [VDS [n] + D1 [s] (VOYLS [n] + VISLS [n])] − HDS [n]
(2.3.8) FHLS [n,s] = HVF [n] [VDS [n] + D2 [s] (VOYLS [n] + VISLS [n])] − HDS [n]
(2.3.9) MAXHTURB [n] = HTUN [n] − HL [n] + HV [n]
(2.3.10) MINHTURB [n] = HTUN [n] − HL [n] + HDS [n]
(2.3.11) MEHTURB [n,s] = HTUN [n] − HL [n] + MEHLS [n,s]
(2.3.12) FHTURB [n,s] = HTUN [n] − HL [n] + FHLS [n,s]

2.4 *Flow and continuity functions* (See Fig. 5)

(2.4.1) QOMER [n,s] = (X[s]/S[s]) VRF2 [n] [VOYLS [n]/Σ QIMEU [n,s]] Σ QIMEU [n,s]
(2.4.2) QOMEU [n,s] = S[s] VRF4 [n] [VOYLS [n]/Σ QIMEU [n,s]] Σ QIMEU [n,s]
(2.4.3) QOFR [n,s] = S[s] VRF3 [n] [VOYLS [n]/Σ QIMEU [n,s]] Σ QIMEU [n,s]
(2.4.4) QIMEU [n,s] = QOMEU [n-1, s] + G[n] QIMEU [1,s]
(2.4.5) QIMER [n,s] = QOMER [n-1, s]

2.5 *Power and energy functions* (See Figs. 5 and 7)

(2.5.1) E [n,s] = KE. MEHTURB [n,s] QOMER [n,s]
(2.5.2) EF [n,s] = KE. FHTURB [n,s] QOFR [n,s]
(2.5.3) PMAX [n] = (Σ E [n,s] × 10³) / (8760 AAVLF)
(2.5.4) PF [n] = (ΣEF [n,s] × 10³) / (8760 PFLF [n])
(2.5.5) PF [n] ≤ PMAX [n]
(2.5.6) SAVLF [n,s] = (E [n,s] × 10³) / (PMAX [n] 8760 S [s])
(2.5.7) BENE [n,s] = VE [s] E [n,s]
(2.5.8) BENFP [n] = VPF PF [n]
(2.5.9) COSTP [n] = CPMAXF [n] [PMAX [n]]
(2.5.10) COSTRANS [n] = (PMAX [n] / ΣPMAX [n]) CTRANSF [Σ PMAX [n]]

Table 3. Definitions of the parameters used

Parameter	Unit	Fig. to be referred to	Definition
AAVLF*	—		Annual average load factor.
B	US$ × 10⁶		Total gross benefits.
BENE [n,s]	US$ × 10⁶		The benefit from average energy production, E [n,s], at site in season s (present value).
BENFP [n]	US$ × 10⁶		The benefit from firm power production, PF [n], at site n (present value).
COSTP [n]	US$ × 10⁶	Fig. 3a	Cost of installed generating capacity PMAX [n], at site n (present value).
COSTRANS	US$ × 10⁶	Fig. 3c	Total cost of transmission capacity, Σ PMAX [n], for the whole scheme (present value).
COSTV [n]	US$ × 10⁶	Fig. 3b	Cost of reservoir storage volume, V [n], at site n (present value).
*CPMAXF [n] [ ]	US$/MW	Fig. 3a	The cost/installed capacity function at site n.
*CTRANSF [ ]	US$/MW	Fig. 3c	The cost/total installed capacity function of the transmission line for the whole scheme.
*COSTVF [n] [ ]	US$ × 10⁶/m³ × 10⁶	Fig. 3b	The cost/total reservoir volume function for site n

Parameter	Unit	Fig. to be referred to	Definition
*D1 [s]	—		Reservoir drawdown factor for season s (average year).
*D2 [s]	—		Reservoir drawdown factor for season s (dry year).
E [n,s]	GWh		The average energy production at site n in season s.
EF [n,s]	GWh		The firm energy production in a dry year at site n in season s.
FHLS [n,s]	m	Fig. 7	The average head in the reservoir live storage zone during season s of a dry year at site n. (Firm live storage head).
FHTURB [n,s]	m	Fig. 7	The average net head acting at the turbines at site n during season s of a dry year (firm net turbine head).
*G [n]	—	Fig. 5	Coefficient of lateral stream inflow between sites n and n-1
HDS [n]	m	Fig. 7a	The head caused by the reservoir dead storage zone at site n.
HISLS [n]	m	Fig. 7a	The maximum head caused by the zone of interseasonal live reservoir storage at site n.

(Continues on next page)

Table 3. Definitions of the parameters used *(Contd.)*

Parameter	Unit	Fig. to be referred to	Definition
HL[n]	m	Fig. 7a	The weighted mean headlosses occurring in the tunnel/penstock system at site n.
LS[n]	m	Fig. 7a	The maximum head caused by the zones of both over-year and inter-seasonal live storage volume at site n.
OYLS[n]	m	Fig. 7a	The maximum head caused by the zone of over-year live storage volume at site n.
HTUN[n]	m	Fig. 7a	The gross head caused by the tunnel/penstock system at site n.
IV[n]	m	Fig. 7a	The maximum head caused by the total (live and dead) storage volume at site n.
KE			Power-to-energy conversion factor.
HVF[n][ ]	$m/m^3 \times 10^6$	Fig. 7a	The head-storage volume function of the reservoir at site n.
MAXHTURB[n]	m	Fig. 7a	The maximum net head acting on the turbines at site n.
MEHLS[n,s]	m	Fig. 7a	The mean head occurring in the total live storage zone during season s at site n.
MEHTURB[n,s]	m	Fig. 7a	The mean net head acting on the turbines at site n.
MINHTURB[n]	m	Fig. 7a	The minimum net head acting on the turbines at site n.
[n]	—		Parameter suffix denoting site.
PMAX[n]	MW		The maximum power capacity, ie, installed turbine capacity, at site n.
PVF[n]	—		Present value factor for costs and benefits of site n.
FP[n]	MW		The minimum power output at site n during the dryest month on record, ie, the firm power output
FPLF[n]	—		The load factor at which the firm power, FP[n], is produced at site n.
QIMER[n,s]	$m^3 \times 10^6$	Fig. 5	The mean regulated inflow to site n from site n-1 during season s.

Parameter	Unit	Fig. to be referred to	Definition
QIMEU[n,s]	$m^3 \times 10^6$	Fig. 5	The mean unregulated inflow to site n (spill from site n-1 and lateral inflow between sites n and n-1) during season s.
QOFR[n,s]	$m^3 \times 10^6$	Fig. 5	The mean regulated (turbine) discharge at site n, during season s of a dry year (firm regulated discharge).
QOMER[n,s]	$m^3 \times 10^6$	Fig. 5	The mean regulated (turbine) discharge at site n during season s.
QOMEU[n,s]	$m^3 \times 10^6$	Fig. 5	The mean unregulated discharge (spill) at site n during season s.
*S[s]	—		Seasonal coefficient for winter and summer (expressed as a fraction of the year).
[s]	—		Parameter suffix denoting season.
UCE[n]	mill/kWh		Average unit cost of energy for site n.
*UCEF	—		Conversion factor for obtaining unit cost of energy.
V[n]	$m^3 \times 10^6$	Fig. 7a	The total reservoir storage volume at site n.
VDS[n]	$m^3 \times 10^6$	Fig. 7a	The volume of dead storage of reservoir n.
*VDSMIN[n]	$m^3 \times 10^6$	Fig. 7a	The minimum dead storage volume required for sediment retention at reservoir n.
*VE[s]	mill/kWh		The unit value assigned to energy generated in season s.
VISLS[n]	$m^3 \times 10^6$	Fig. 7a	The volume of the inter-seasonal live storage zone at reservoir n.
VMAX[n]	$m^3 \times 10^6$	Fig. 7a	The maximum feasible total (dead plus live) storage volume at reservoir n.
VOYLS[n]	$m^3 \times 10^6$	Fig. 7a	The volume of the over-year live storage zone of reservoir n.
*VFP	$/kW-year		The unit value assigned to firm power generation.
YF[ ]	—	Fig. 4	Reservoir yield function.
*X[s]	—		Inter-seasonal storage shift factor.

* Values given as basic input data.

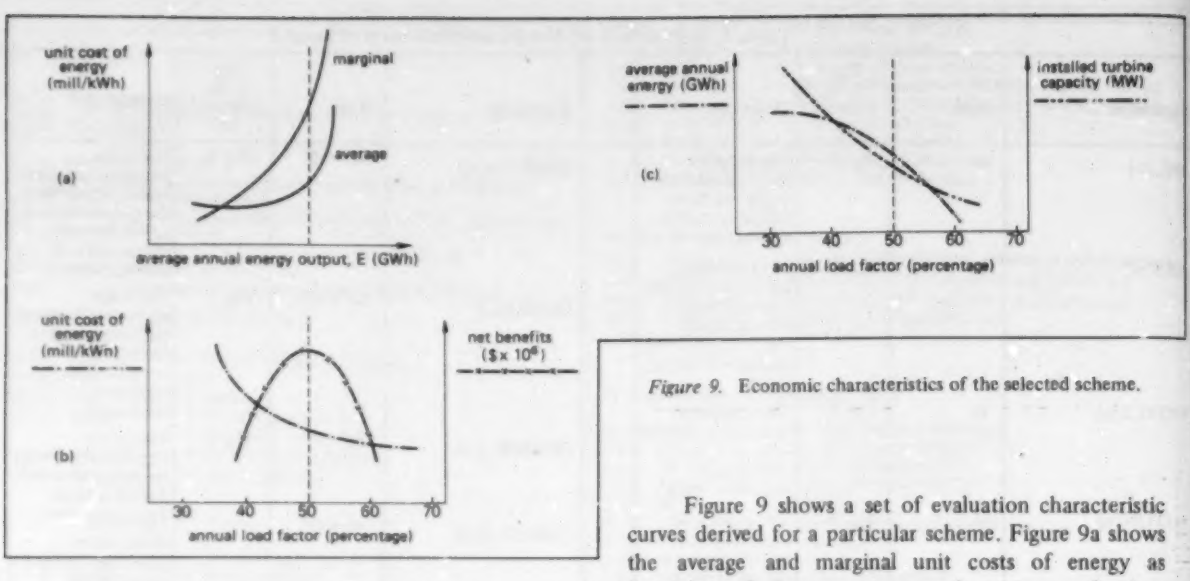

Figure 9. Economic characteristics of the selected scheme.

Figure 9 shows a set of evaluation characteristic curves derived for a particular scheme. Figure 9a shows the average and marginal unit costs of energy as functions of the average annual energy production. Figure 9b gives curves of average unit cost of energy and net benefits, and figure 9c average energy production and installed turbine capacity, all as functions of annual load factor.

Evaluation results

Typical evaluation results for a pre-feasibility screening exercise are shown in figure 8. Here the evaluation indices, net benefits and unit cost of energy are given for each scheme in the form of a histogram. The net benefits and unit costs given are for the optimized schemes in each case. The best scheme can easily be seen.

Such sets of characteristic curves as illustrated in figure 9 are useful in indicating how the selected scheme would best operate within the context of the total system, giving broad guidelines for the next, more detailed design and evaluation stage in which full simulation and load allocation modelling would be carried out.

A philosophic excerpt from an opening address at a conference of hydraulicians in India

Throughout the history of mankind, great civilizations have flourished only where water has been cherished as a caring mother, respected as a powerful enemy, and managed as the storehouses of treasures which the rivers and seas truly are. Therefore, it is wonderfully appropriate for an international congress of hydraulicians to be convened in India, for nowhere can one find a society with a grander tradition of water management, for a culture which is richer in its water lore.

It is interesting to learn, for example, that in Hindu mythology, rivers are considered to be sacred. This is seen in the Rigveda, one of the earliest Hindu scriptures, where we find the statement "*aapo devihi*" ("all rivers are goddesses"). Some Hindu prayers even include a recitation of names of rivers. In these the River Ganges is referred to as "Mother" Ganges, and is revered as so holy that its water gives eternal life to those who drink it, and so treasured that a famous Chola King, after conquering the whole north of India, wanted as spoils of war no more than a perpetual supply of Ganges water for the temple of Gangai Konda Chola Puram.

I am also told that the major rivers on the Indian subcontinent, except the Brahmaputra, are feminine in gender. Thus it appears that the Hindu sages clearly understood the common nature of rivers and women. Both can be trained, but neither can be controlled. Both of them sustain and perpetuate the life of man, but either can lead to his ruination. Either can be equally seductive and vicious. And both have about them an air of mystery which leads men to fantasy, for just as the sacred Saraswati River, which is believed to join the Ganges and Yamuna Rivers at Allahabad, exists not physically but only in mythology, so does there exist in the mind of every man the woman who is perfect for him– the one who is of unequalled beauty and who is his boundless source of unending happiness and complete fulfillment. I refer, of course, to our wives.

SOURCE: "A letter to the IAHR membership from the President", Newsletter No. 7 (September 1981), *Journal of Hydraulic Research*, IAHR, vol. 19-1981-No. 3.

OPTIMUM DESIGN FLOOD FOR SPILLWAYS

F.E. Fahlbusch[1]

Designing the optimum size for a spillway should be based on rational economic analysis, the author argues. This is only rarely carried out because of a natural reluctance to assign a monetary value to human life, but this approach simply ignores rather than resolves the difficulty. After evolving a rational basis, the author then compares existing installations with the developed paradigm.

Today's decision-making process for spillway design is governed by the need to meet an increasing demand for goods and services under the constraints of limiting funds and diminishing resources. The prevention of waste of any kind of resources has therefore become the central criterion for this process.

Although thousands of spillways have been designed and constructed all over the world during this century, relatively little is actually known about them; they may be only marginally safe, or unduly conservative in design.

Spillways for dams, especially embankment dams, are expensive and may be the critical factor in deciding on the economic feasibility of water resource projects. In adverse circumstances, the spillway cost may exceed the cost for the embankment dam itself, and even in normal circumstances, spillway costs below 40 to 80 per cent of the dam costs are not common.

In spite of the immense expense, progress toward more cost-effective technology has not advanced in pace with needs. The design of embankment structures resistant to occasional overtopping is still at a premature stage, and there does not seem to be much prospect of the development of cost-reducing structural improvement in the design and construction of spillways.

An obvious obstacle against achieving more economic spillway designs seems to be the lack of contemporary design criteria commensurate with the present state of knowledge, and consistent with design standards and factors of safety applied and accepted by societies in other areas, such as traffic safety. It is partly this gap which prevents full advantage being taken of the potential offered by new techniques available in flood flow analysis, a field in which there has been substantial progress in recent years.

The problem of determining the spillway design flood is usually approached in four ways: engineering judgement, risk analysis, probable maximum flood concept and economic analysis. Which type is ultimately chosen depends, among other things, on the planner's individual preference and attitude to risk.

The engineering judgement-based approach uses as the design flood the largest historical flood multiplied by a factor larger than unity chosen on the grounds of engineering judgement. In the risk analysis, admissible risk level is assessed beforchand, generally by qualitative reasoning on the grounds of economic, social, political engineering and other factors. With such a predetermined risk level and the estimated service life of the project, the design return period and then the associated design flood discharge[2] are determined.

The probable maximum flood approach attempts to establish an upper limit of the flood potential through maximization of a combination of critical meteorological elements. It has been in use for a long time especially in connection with the design of large embankment dams, but as Benson[3] noted recently, not because of its merits, but simply because it provides the easiest way out of a delicate decision problem.

In fact, the premise of the method is vague. Inherent is the questionable assumption of the availability of unlimited funds to provide full security for all members of society. More important, is that it purports to provide complete safety, which with the present state of knowledge and understanding of the complex phenomena involved in the flood formation process cannot really be guaranteed.

The economic approach, balancing the cost of providing protection against losses that would occur when protection is insufficient, is more consistent with the modern view of decision making with the constraint of scarce resources, because it gives proper weight to the economic implications of the scarcity. Despite its rational basis, this approach has apparently only been applied occasionally, although its basis has been fully explored for some time.[4] The apparent aversion to the

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1 Chief Resident Engineer at Lahmeyer International GmbH, Frankfurt/Main at the time of original publication; currently, at International Engineering Co., Inc., San Francisco, California. This article was originally published in *Water Power & Dam Construction* (ISSN 0306–400X; vol. 31, No. 11, November 1979). It is reprinted here with permission from the publishers and the author, who has made a few emendations to the published text. Copyright 1979 by IPC Business Press Ltd.

2 B.C. Yen, "Risk in hydrologic design of engineering projects", *Journal of the Hydraulic Division*, ASCE, vol. 96, No. HY 4, Proceedings Paper 7229 (April 1970).

3 M.A. Benson, "Thoughts on the design of design floods", *Floods and Droughts*, Proceedings of the Second International Symposium in Hydrology (Fort Collins, Colorado, 1973).

4 E. Kuiper, "Water resources development", Butterworths, London, England; 1965. T. Au, R.M. Shane and L.A. Hoel. *Fundamentals of System Engineering: Probabilistic Models* (Reading, Massachusetts, Addison-Wesley, 1972).

economic approach seems to stem from the possible necessity of assigning monetary values to human lives if a loss of life is to be expected in the event of a failure. Although the difficulties in assigning a monetary value to human life are recognized, it must be realized at the same time that the inherent arbitrariness in any other method in selecting directly or indirectly the level of safety does not resolve the issue, but assumes the problem away.

Freudenthal[5], in studies on the safety and reliability of larger engineering structures, found that the optimum level of structures in which the cost of failure does not greatly exceed that of replacement is, in terms of the probability of failure, of the order of 10^{-2}. He has further shown that if the cost of failure includes additional economic losses beyond the replacement cost, the level of safety reduces to about 10^{-3}. Only when human lives are endangered, will a higher level of safety result, the order of which depends on the number of lives threatened and the monetary value assigned to them.

The objective of this paper is to examine the optimum level of safety to be provided in spillways of large embankment dams. The relationships between the optimum level of safety and the economic consequences are first explored theoretically from the economic approach and then they are examined on the basis of real design data.

Theoretical analysis

(a) *The economic model.* The subsequent derivation of the condition of the optimum level of safety is along the lines of work by Dantzig[6], and Shane and Gaver[7]. Similar models have also been elaborated by Rundgren[8] and Duffaut, *et al*[9].

The objective in selecting the optimum design or level of safety is to minimize the total loss over a long period of time. The costs comprise those for providing protection and those for damage resulting from a hypothetical failure of the spillway if the level of protection or the capacity is insufficient. The problem belongs to the class of "decision-making under risk", because the damage (and in turn the total loss) are random variables. Although it might not be the most appropriate one, (and in fact there are good arguments against it), the expected value criteria applied to the total loss was used in this study as a working hypothesis.

Since damage will only be incurred after the investment for construction is made, future damage must necessarily be discounted to allow for the time value of money and to obtain the expected present worth of damage is added to the construction costs to obtain the expected present worth of the total losses associated with the provision of a particular level of protection.

The objective function to be minimized to obtain the optimum level of protection is:

$$E(\text{pwl}) = C(x) + \sum_{i=1}^{n} E(D_i)/(1+r)^i \quad \ldots\ldots\ldots \quad (1)$$

Subsequently, it is assumed that

(i) Recurrence of more than one event in any given year causes no additional damage;

(ii) Probability of one or more floods in excess of the design level in a year is constant from year to year; and,

(iii) Damage is fixed and does not depend on the magnitude of the floods.

The last assumption, implying complete destruction whenever the design discharge is exceeded even by the smallest amount, is a somewhat unreal assessment and should be relaxed whenever circumstances permit assessing the resistance of embankment dams subject to occastional overtopping. Also, a more advanced analysis would have to distinguish between a small excess above the design flood and a large one, because the small excess is unlikely to produce the same damage as an event whose discharge exceeds the spillway design capacity by a substantial amount.

With the above assumption and considering that the expected damage is by definition $E(D) = D\,F(x)$, where $F(x)$ is the exceedance probability $P(X \geq x)$ of the natural or reservoir-routed flood flow; and X designates the random variable and x the value the variable can take, and also assuming that protection is provided for an infinite period of time, then equation 1 becomes:

$$E(\text{pwl}) = C(x) + DF(x)/r \quad \ldots\ldots\ldots \quad (2)$$

The optimum level of protection is found by differentiating equation 2 with respect to x and setting the resulting expression equal to zero.

$$dC(x)/dx + (D/r)(dF(x)/dx) = 0 \quad \ldots\ldots\ldots \quad (3)$$

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5 A.M. Freudenthal, "Safety and reliability of large engineering structures; public safety: a growing factor in modern design", Symposium of the National Academy of Engineering, National Academy of Sciences, Washington, D.C. (1970).

6 D. Van Dantzig, "Economic decision problems for flood prevention", *Econometrica*, No. 24 (1956).

7 R.M. Shane and D.P. Gaver, "Determination of optimum flood protection levels with small exceedance probabilities", *Water Resources Research*, No. 6 (December 1969).

8 L. Rundgren, "Design floods and accepted risk of failure", Eleventh Congress of Large Dams, Madrid, Spain (1973).

9 J. Duffaut and others, "Determination des Crues de Project", *ibid*.

which under consideration that the derivation of the probability function is the probability density function of $f(x)$ yields:

$$C'(x)/(D/rf(x)) = -1 \qquad \ldots\ldots\ldots \quad (4)$$

where the dash (') denotes the derivative of the function $C(x)$ with respect to the variable x.

(b) ***The cost function.*** The cost function, $C(x)$, of a spillway is usually not only a function of the flood flow, but depends on a large number of diverse factors encountered in reality. Often, the function is only partially continuous; because of specific site conditions discontinuities are the rule rather than the exception. For instance, small and medium floods may be controlled safely by small-scale enlargements of the diversion works at little extra costs, while floods larger than a certain magnitude may necessitate the provision of a separate spillway at comparably high costs.

Despite the limitations, a general analysis necessitates the adoption of an appropriate functional form. The linear relationship between the costs and the discharge capacity as well as the power function are acceptable approximations. The choice between both is a matter of analytical expediency, mathematical convenience and the advantage either one may offer under specific circumstances.

The power function:

$$C(x) = bx^m \qquad \ldots\ldots\ldots \quad (5)$$

was chosen in this context, for mathematical convenience and also because of the advantage it offers in the fitting of the model to the real data used in the second part of this study.

(c) ***The probability function.*** Since the introduction of the probability analysis into hydrology, a substantial number of probability models for the prediction of flood flow have been proposed, explored and tested and their practicality, advantages, disadvantages, strength and weaknesses have been discussed at length. Each of the variuos models rests on certain assumptions, which can hardly be tested in the sense of physical research, since the available flood records are typically too short.

Two models, which have been subject of extensive tests over the years and for which some reasonable theoretical and empirical evidence of broader applicability has been provided are the Gumbel and the log-normal models. The Gumbel model has been selected for the purpose of this analysis, since for rare events, it can be advantageously simplified without loss of accuracy. For events with a return period T greater than about 10 years, the true functional relationship between the frequency factor k and the return period T is

$$k = \sqrt{6}/\pi\,[0.5772 + \ln \ln(T/[T-1])]$$

which can, without giving rise to serious errors, be expressed approximately in the form of a simple linear relationship

$$k = \eta \ln T - \epsilon \qquad \ldots\ldots\ldots \quad (6)$$

in which the two parameters η and ϵ vary with the sample or length of the records. For records comprising 10 or more years of observations, η takes on approximately the value 1.0 and the numerical value for ϵ is close to 0.6.

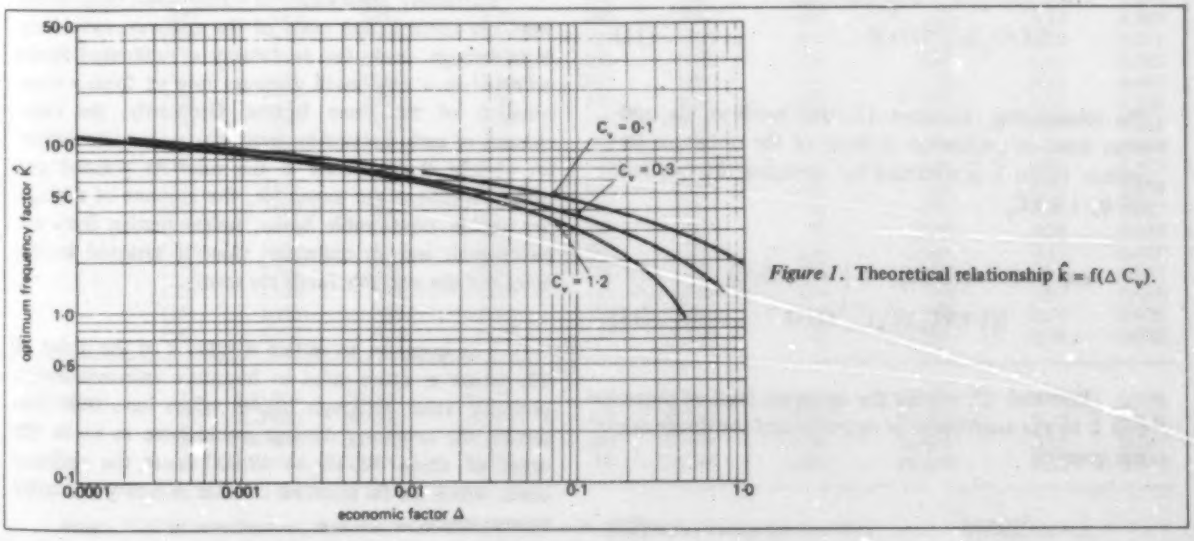

Figure 1. Theoretical relationship $\hat{k} = f(\Delta\, C_v)$.

Inserting the relationship between the return period and the probability of exceedance $T = 1/F(x)$ and the generalized equation for hydrologic frequency analysis $x = \bar{x} + k\sigma$, (where $\bar{x}$ = the average flood and σ = the standard deviation) into equation 6, yields, after some mathematical manipulation:

$$F(x) = \lambda \exp(-x/\sigma) \quad \ldots\ldots\ldots (7)$$

and

$$f(x) = -\lambda/\sigma \exp(-x/\sigma) \quad \ldots\ldots\ldots (8)$$

with

$$\lambda = \exp(1/C_v - \epsilon) \quad \ldots\ldots\ldots (9)$$

where C_v = the coefficient of variation of the flood flow.

(d) *Optimum frequency factor.* The optimum level of protection or safety level can be expressed in the form of several interrelated indices each carrying the same information content such as in terms of the optimum frequency factor $\hat{k}$. The latter is particularly useful because it combines in one single quantity three significant factors: the optimum design flood $\hat{x}$, the average flood $\bar{x}$ and the standard deviation.

Inserting equation 8 and the derivative of equation 5 into equation 4, yields the implicit equation for the optimum level in terms of the flood flow:

$$mbx^{m-1} = \lambda/\sigma \exp(-x/\sigma)(D/r) \quad \ldots\ldots\ldots (10)$$

At the optimum level, $x = \hat{x}$ and $C = \hat{C} = b\hat{x}^m$ where $\hat{C}$ is the cost for the spillway associated with the optimum design flood which by combination with equation 10 and considering $\sigma = C_v\bar{x}$, where C_v is the coefficient of variation, results in the following relationship.

$$\exp[-\hat{x}/C_1\bar{x}] = (m\hat{C})/(D/r)]$$
$$[\hat{x}/C_1\bar{x})^{-1}(1/\lambda)] \quad \ldots\ldots\ldots (11)$$

The relationship, equation 12, that holds at the optimum level of protection in term of the optimum frequency factor $\hat{k}$ is obtained by replacing the quotient $\hat{x}/\bar{x}$ by $1 + \hat{k}C_v$.

$$\exp[-(1 + \hat{k}C_v)/C_v] = [(m\hat{C})/(D/r)]$$
$$[(1 + \hat{k}C_v)/C_v]^{-1}(1/\lambda) \quad \ldots\ldots\ldots (12)$$

Equation 12 relates the optimum level of protection $\hat{k}$ to the coefficient of variation and the dimensionless quantity

$$\Delta = m\hat{C}/(D/r) \quad \ldots\ldots\ldots (13)$$

which can be regarded as an overall economic index of the problem. The index Δ unites in one single entity all the economic factors involved, that is:

(i) Cost for providing the optimum level of safety;

(ii) Discounted damage resulting for failure if the design is insufficient; and,

(iii) Discount rate which, as a measure of the opportunity cost of the capital, reflects the scarcity of the money.

(e) *Discussion of the relationship* $\hat{k} = f(\Delta, C_v)$. The relationship between the optimum frequency factor, the economic variable and the coefficient of variation, defined by $\hat{k} = f(\Delta C_v)$ and determined by numerical solution of equation 12, is shown in figure 1, for a range of Δ from 10 to 0.00001 and for C_v from 0.1 to 1.2.

The graphs show that the optimum level of protection is related inversely to both the economic variable Δ and the coefficient of variation.

While the influence of C_v on $\hat{k}$ tends rapidly to approach limiting values (for C_v larger than about 0.3 which is usually the case in practice, the influence of C_v is practically negligible) $\hat{k}$ increases without limit with decreasing Δ. From equation 12, it can be deduced that $\hat{k}$ converges to its limit $\hat{k} = \Delta$ as Δ approaches to zero.

The most significant property is the extraordinary mild gradient of the relationship $\hat{k}$ versus Δ which implies, on the one hand, a poor convergence of the optimum frequency factor to its limiting value and, on the other, that higher levels of protection require exceedingly small values of the economic variable.

Extremely small values of Δ may result from either very low construction costs of the spillway, extremely high damage and the availability of unlimited funds reflected in a very small discount rate or from a combination of the three factors. Ordinarily, the coincidence of such favourable circumstances is quite unlikely; usually the opposite is the rule. As pointed out earlier, spillways are expensive, the amount of damage lies within conceivable limits, unless human lives are endangered and an unlimited value is assigned to the lives, and the available funds are scanty.

For instance, to obtain a value $\hat{k}$ of the order of 15, which is often cited in literature as a maximum probable value although higher values have been observed, the necessary damage would have to be in the order of about 30,000 to 40,000 times the spillway costs, which are far in excess of what in reality is usually encountered.

Optimum level of safety derived from project data

The project catalogue comprises real project data from 24 hydro-electric development projects supplemented by a hypothetical scheme. The motivation for inclusion of the hypothetical scheme has been to cover a broader spectrum of project scales beyond those defined by the 24 projects. Although these projects differ substantially from each other in certain specific features, on the whole they are only of average scale in terms of costs and energy potential. For guidance in the specification of the hypothetical scheme, reference was made to the largest hydro-electric developments at present under construction to minimize abstraction and to reflect reality more closely.

The relevant data concerning the real projects were extracted from two reports on hydro-electric development in the Philippines[10]. Each of them was dealt with on a prefeasibility level, using the same design and planning principles and standards. Individual designs were developed considering specific site conditions and the costs were estimated on a unit price basis. The dams of all the schemes are the embankment type and the spillways are of the open chute type with grated weirs. The spillway design discharges range from 1,200 m^3/sec to 14,000 m^3/sec. In this study, each project is considered in isolation disregarding the actual multisite development in some river basins. Hazard to human life and property as well as loss of human life has not been considered as this study focuses, in the first instance, on examining the optimum economic design floods and the optimum economic level of safety on purely economic grounds.

The damage was assumed to consist of the cost of reconstruction of the dam, the diversion work and the spillways; compensation for the interruption of energy production during the hypothetical years of outage covering years for planning and reconstruction. During the period that the hydroplants are out of operation, the make-up energy was assumed to be provided from fuel-fired plants. Inflation effects were considered as self-balancing, that is the value of damage was time-invariant. The economic horizon was assumed to be infinite and a discount rate of 10 per cent was employed.

In table 1 salient characteristics of the actual projects as well as those relative the hypothetical scheme are listed.

10 "Report on the Agus River system study", Lahmeyer International Consulting Engineers, Frankfurt (Main), Federal Republic of Germany (Manila, Philippines; 1976). "Report on the power generation expansion study, Luzon", *ibid.* (1977).

Table 1. Project catalogue and features

Project name		*Catchment area (km^2)*	*Average flood (m^3/sec)*	*Specific average flood (m^3/sec km^2)*	*Dam height (m)*	*Energy output (GWh/a)*	*Cost* ($US x 10^6)*	*Damage ($US x 10^6)*	*Ratio spillway/ dam cost*	*b*
Real Schemes	(1)	765	2200	2.88	130	900	140	360	0.82	0.105
	(2)	1550	2850	1.84	110	1640	190	590	2.15	0.098
	(3)	385	1000	2.60	195	540	165	290	0.24	0.053
	(4)	440	1050	2.39	140	230	165	220	0.38	0.071
	(5)	565	1200	2.12	150	380	200	315	0.36	0.073
	(6)	820	1400	1.71	110	375	130	225	0.85	0.075
	(7)	1235	1650	1.34	100	480	150	270	0.89	0.080
	(8)	875	1450	1.66	160	570	260	420	0.42	0.096
	(9)	460	1050	2.28	140	325	180	250	0.34	0.069
	(10)	615	1950	3.17	200	675	440	630	0.20	0.071
	(11)	355	1150	3.24	165	790	250	445	0.41	0.105
	(12)	1410	1550	1.10	155	850	215	450	0.41	0.067
	(13)	1245	2400	1.93	200	850	450	740	0.33	0.101
	(14)	590	410	0.69	195	675	390	510	0.07	0.065
	(15)	895	480	0.54	110	515	180	290	0.10	0.038
	(16)	1045	500	0.48	75	440	50	125	0.40	0.027
	(17)	4800	720	0.15	105	1240	80	325	0.32	0.049
	(18)	3800	680	0.18	115	1100	50	270	0.30	0.027
	(19)	1400	570	0.41	115	460	70	160	0.34	0.039
	(20)	760	460	0.61	185	550	175	300	0.17	0.059
	(21)	1500	620	0.41	130	750	180	350	0.13	0.047
	(22)	1500	620	0.41	70	480	50	135	0.57	0.040
	(23)	1875	300	0.16	32	880	7	180	2.30	0.025
	(24)	1775	300	0.17	100	1175	40	280	0.26	0.023
Hypothetical Schemes:	(1)	800 000	30 000	0.038	180	70 000	3500	26 000	0.05	0.046
	(2)	800 000	30 000	0.038	180	70 000	3500	26 000	0.10	0.091
	(3)	800 000	30 000	0.038	180	70 000	3500	26 000	0.15	0.137
	(4)	800 000	30 000	0.038	180	70 000	3500	26 000	0.20	0.183

Note: * Cost covering dam, diversion work and spillways including interest during construction.

Spillways usually exhibit economy of scale, which limits the exponent [m] to values less than or equal to unity. But within the range $0 \leqslant m \leqslant 1$, it varies in general from project site to project site depending on the specific situation encountered in reality. A more accurate assessment of [m] would have required undertaking several designs for a number of discharges.

On the other hand, specific site conditions can approximately be accounted for either in the exponent [m] or in the coefficient [b] of the cost function. In the development of the scheme, designs for some possible spillway shapes for different discharges were carried out on a preliminary level, for some of the projects. When they were examined they revealed an exponent [m] of approximately 0.75, which was subsequently assumed to be applicable to all projects as a constant. Unlike the exponent [m], the coefficient [b] was determined for each individual project from the spillway costs developed in the studies and the associated design floods. As a consequence of the large variety of site conditions, the coefficient can vary within a wide margin (table 2).

Table 2. Optimum level of safety

Project name		*Economic factor*	*Frequency factor*	*Return period (years)*	*Probability*
Real schemes	(1)	0.0178	5.08	249.1	0.003 40
	(2)	0.0153	5.53	460.9	0.002 17
	(3)	0.0082	6.25	946.8	0.001 06
	(4)	0.0139	5.65	517.3	0.001 93
	(5)	0.0116	5.86	638.8	0.001 57
	(6)	0.0178	5.36	387.8	0.002 58
	(7)	0.0180	5.35	384.0	0.002 60
	(8)	0.0130	5.73	560.2	0.001 79
	(9)	0.0122	5.80	602.0	0.001 66
	(10)	0.0084	6.23	925.4	0.001 08
	(11)	0.0114	5.87	647.5	0.001 54
	(12)	0.0092	6.13	838.3	0.001 19
	(13)	0.0114	5.88	650.3	0.001 54
	(14)	0.0034	7.25	2558.3	0.000 39
	(15)	0.0039	7.09	2194.6	0.000 46
	(16)	0.0062	6.56	1282.1	0.000 78
	(17)	0.0057	6.65	1411.0	0.000 71
	(18)	0.0038	7.11	2221.2	0.000 45
	(19)	0.0075	6.34	1033.6	0.000 97
	(20)	0.0055	6.70	1479.7	0.000 68
	(21)	0.0047	6.87	1759.9	0.000 57
	(22)	0.0095	6.07	788.9	0.001 27
	(23)	0.0020	7.99	5297.9	0.000 19
	(24)	0.0013	8.50	8950.1	0.000 11
Hypothetical schemes	(1)	0.0008	9.04	15 295.0	0.000 07
	(2)	0.0015	8.34	7620.0	0.000 13
	(3)	0.0022	7.92	5815.0	0.000 20
	(4)	0.0029	7.62	3730.0	0.000 27

It should be noted that the assumed features of the hypothetical schemes are on the whole conservative in the sense that both individually and in combination they tend to generate a level of safety on the conservative rather than otherwise.

Results and conclusions

The results were derived by simultaneous numerical solutions of the set of equations (equation 1 to 9) in conjunction with the relationship $\hat{k} = (\hat{x} - \bar{x})/\sigma$. In determining the total amount of damage, it was assumed that in case of failure, the spillways would be destroyed, too. As a result, an iterative procedure was employed starting with an initial value of the spillway costs.

The optimum level of protection for the individual projects in terms of the frequency factor $\hat{k}$ the return period T and the probability P of the design floods are given in Table 2. Table 3 shows the range of the three indices representing the optimum level of safety. In addition, the optimum frequency factor is plotted in figure 2 as a function of the economic factor Δ.

Table 3. Range of indices for optimum safety

Indices		*Range* *Minimum*	*Maximum*
Frequency factor	($\hat{k}$)	5.1	9.0
Return period	(T)	300	15 000
Probability	(P)	$3.4.10^{-3}$	7.10^{-5}

Although the number of projects used in the study is limited, the results nevertheless lead to some valuable conclusions. Firstly, the optimum level of safety for the kind of projects dealt with in this paper are approximately one order of magnitude higher than those for the kind of structures considered by Freudenthal; and secondly, the level of safety for individual projects may vary within a wide margin, depending on the specific situation. Thirdly, even the largest optimum frequency factor derived is substantially smaller than the statistically-based probable maximum frequency factor. And finally, the optimum level of protection, in general, tends to be larger in catchments with low flood producing potentials and vice-versa, as can be inferred from the plot of the optimum frequency factor against the specific average floods of the catchments in figure 3.

In view of the wide variation of the optimum level of safety, it would not seem adequate to specify rigid design standards such as in terms of a specific probability value, which reflects only one part of the issue. A standard must, in one way or another, be related to the social and economic consequencies; otherwise, the arbitrariness in the design flood decision remains unresolved.

Although the social side of the problem warrants careful consideration, and its inclusion in the ultimate decision process may not be an easy task because of the possible emotive objections in assigning a monetary value to human lives, it is suggested that the economic approach should constitute the first step. It permits a

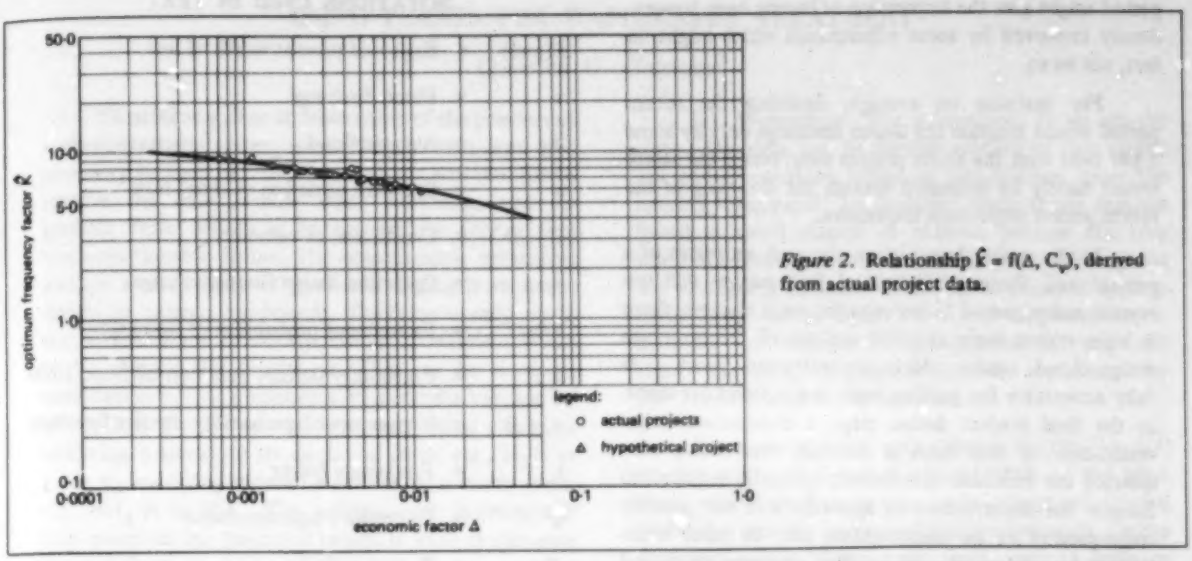

Figure 2. Relationship $\hat{k} = f(\Delta, C_v)$, derived from actual project data.

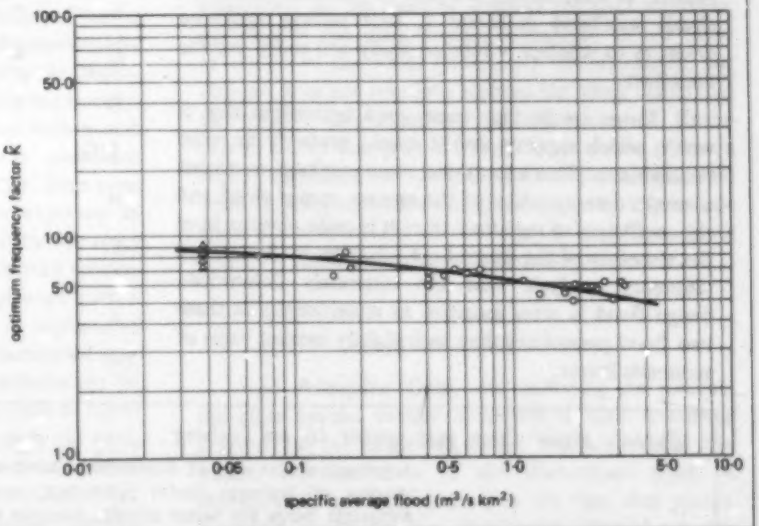

Figure 3. Optimum frequency factor versus specific flood.

rational basis and an objective starting point to be established by removing a substantial part of the usual arbitrariness. The final decision, which additionally incorporates the economic, engineering and social aspects will be greatly facilitated once the potential of the economic approach has been fully exploited.

It is a common observation that the objective function (equation 1) is usually rather flat in the neighbourhood of the optimum; thus the minimum expected present worth of the total losses is not exceedingly sensitive to deviations from the optimum. A study of the behaviour of the objective function around the economic optimum will therefore provide a beneficial insight into the interrelationship between the various factors involved. Under favourable circumstances, the level of safety can greatly be increased for little extra cost.

Such sensitivity studies should preferably be made in terms of the frequency factor or the optimum design flood, simply because the probability value or the return

period might give the impression of having been tremendously improved by some adjustments which might, in fact, not be so.

For instance on average, doubling the return period would increase the design discharge only by some 5 per cent with the above project data; that is the safety would hardly be increased though the doubling of the return period might look impressive.

In the early phases when the cost estimates of a project and those of individual features are still uncertain and expected to undergo the usual changes, there is little reason for a detailed analysis of the optimum design flood, under which circumstances figure 1 is fully acceptable for guiding basic design flood decisions. In the final project design stage, a comprehensive investigation of this issue is basically warranted, considering the immense investments generally required to finance the construction of spillways and the possible consequences of an inappropriate size. In many situations it would indeed seem prudent to assess, value and give due weight to the peculiarities governing a particular situation, rather then to depend solely on a curve resting on certain premises and assumptions. On the other hand, the value of the optimum frequency factor is not very sensitive to even a wider variation of the economic factors, at least not in the part of practical interest as clearly exhibited in figure 1, thus leaving legitimate doubt as to whether a detailed study will really pay for the effort.

There are in fact some good indications that it won't, which suggests that it would probably be more profitable to place a great deal more emphasis on a most accurate determination of the average annual flood and the coefficient of variation, since it is quite obvious from the structure of the generalized equation for hydrologic frequency analysis that the ultimately determined design flood is more sensitive to uncertainties in these two flood parameters than to a slightly inexact value of economic factor.

NOTATIONS USED IN TEXT

$E(\text{pwl})$	=	Expected present worth of loss
x	=	Flood discharge
$\bar{x}$	=	Average flood
σ	=	Standard deviation of flood flow
C_v	=	Coefficient of variation
$\hat{x}$	=	Optimum design flood discharge
$F(x)$	=	Exceedance probability of flood flow
$f(x)$	=	Probability density function of flood flow
ϵ, η, λ	=	Parameters of probability density function
k	=	Frequency factor
$\hat{k}$	=	Optimum frequency factor
T	=	Return period
$\hat{T}$	=	Optimum return period
$C(x)$	=	Spillway cost function
m	=	Exponent of spillway cost function
b	=	Coefficient of spillway cost function
$\hat{C}$	=	Optimum spillway costs at $x = \hat{x}$
D	=	Damage associated with failure
$E(D)$	=	Expected damage
n	=	Planning horizon
i	=	Integer denoting any one year within the planning horizon
r	=	Discount rate
Δ	=	Economic factor, $m\hat{C}/Dr$

There's more than just water to an iceberg . . .

A project under way at Australia's University of Melbourne is studying the melting process of icebergs under laboratory conditions in preparation for the use of Antarctic bergs for water supply. Various studies have been made of the feasibility of bringing icebergs from the Antarctic through different ocean current systems to western Australia. The Melbourne project is based on the premise that much more needs to be known about the melting process before such a project is undertaken.

SOURCE: *Water Resources Bulletin*, AWRA, June 1981

. . . energy, too

A technique for producing fresh water and mechanical energy from melting icebergs has been granted patent 4,295,333. Awarded to Wayne M. Camirand, John M. Randall and Earl Hautala of the Department of Agriculture Research Center, Berkeley, Calif., the patent describes evaporating warm surface water by pumping it into a vacuum. The vapor operates a turbine, producing electrical energy. Condensing the vapor by cold water from the iceberg then allows the mixture to be used to melt the iceberg itself. Added moisture from the vapor creates a larger volume of fresh water than that produced by melting the iceberg alone. The procedure has not yet been followed but interest has been expressed in towing small icebergs from Antarctica to water-poor nations in the Middle East.

SOURCE: *Water Newsletter*, WIC, vol. 23 No. 21 (19 November 1981)

USING PLANTS FOR WASTEWATER TREATMENT

Clarence G. Golueke[1]

To achieve a clear understanding of the position of a photosynthetic system in wastewater treatment, it is necessary to keep in mind that the basic goal is either to remove the objectionable waste substances and organisms from water, or to convert the former into non-objectionable forms. The objectionable substances include a wide array of materials ranging from heavy metals to organic compounds. The latter usually are in the reduced state. Obviously, the ideal treatment would be to remove the substances. This can be done by assimilation by living organisms, by precipitation, and by adsorption. Conversion can be accomplished either by oxidizing material to its elemental form, e.g., H_2S to S, or by oxidizing reduced elements to a stable form, e.g., NH_4-N to NO_3. The problem with conversion is that many of the oxidation products serve as nutrients for undesired plant growth in bodies of water receiving them (i.e. eutrophication).

A solution to the problem of converted waste products being further transformed into uncontrolled plant growth is to convert them to plant material under controlled conditions, either during the treatment process or immediately prior to discharge. Since a distinguishing feature of plant life is photosynthesis, this is where photosynthesis comes into play. In photosynthetic systems, plants serve as scavengers and thereby carry on two functions of treatment, conversion and removal. Systems can be devised in which the plants are inserted at any point in the treatment flow. Thus even raw sewage can be effectively treated by exposure to plants, although oversize particles should be removed from raw sewage before processing. If inserted further down the treatment line, the function of plants becomes one of removing the materials stabilized or oxidized in the preceding treatment steps. Heavy metal removal may be accomplished either through direct assimilation by the plants or indirectly through the formation of insoluble complexes brought about by a change in pH level, which in turn is a result of plant growth. Plant mateial produced in the treatment process is harvested either periodically or continuously. Harvesting constitutes the final removal.

CLASSIFICATION OF SYSTEMS

Type of plants used in treatment depends upon the particular system being used. The range is extremely wide, namely from the lower plants (e.g. algae) to the higher vascular forms (e.g. water hyacinths). For convenience of discussion the plants may be divided into two broad groups: microscopic and macroscopic.

(a) *Microscopic.* The microscopic forms are the algae. The algae can be further subdivided into single-cell and filamentous types. In this division under the heading "single-cell" are included those forms that are found in small clumps or packets, because like true single-cell forms, they tend to be dispersed throughout the suspending medium. Therefore in practical applications, they can be treated like true single-cell types. *Chlorella* and *Euglena* are examples of the single-cell algae. The clump or packets types are represented by the various species of *Scenedesmus.*

Filamentous forms may exist as minute (i.e. 100 to 500 microns) filaments characteristic of the blue-green alga *Spirulina* to the large masses of tangled threadlike growths as exemplified by *Spirogyra.* Unlike single-cell groups, filamentous forms tend to settle or aggregate in localized areas. Otherwise, unless they are attached to rocks or other objects, they tend to form floating masses buoyed by trapped gases.

(b) *Macroscopic.* The macroscopic group is made up of vascular plants (angiosperms). It is further subdivided on the basis of whether the photosynthetic portions of the plant remain submerged in the water or are above the water (emergent). Unfortunately, this division does not take into account the many plants that are partially submerged and partially emergent. Examples of plants that grow well on sewage are the common reed *Phragmites communis,* the bulrush *Scirpus lacustris,* water hyacinths, duckweeds (*Lemna spp.* and *Spirodella spp*), forms of elodea (*Elodea canadensis,* etc.), *Egeria densa,* hydrilla, and *Cerato-phyllum demersum.*

Algal systems

(a) *Principles.* Until, and including the present, the algae species usually employed in algal treatment systems are the single-cell forms, and secondarily the smaller representatives of the filamentous algae. A characteristic of algal systems is the fact that photosynthetic organisms are distributed throughout the suspending medium (the body of wastewater), although they may be more numerous in the zone of light penetration. The dispersion is more uniform when the predominant algae type is non-motile. On the other hand, if motile forms predominate, a layering effect determined by light intensity and penetration takes place.

The mechanism of waste-water treatment (purification) in algal systems is a rather loose symbiosis between algae and bacteria, with algae perhaps being the more dependent of the two in the arrangement. The reason for the greater degree of dependency stems from the inability of algae to utilize complex organic compounds as a nutrient source. Probably the most complex

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[1] Sanitary Engineering Research Laboratory, University of California, Berkeley. This article was originally published in *Compost Science* (vol. 18, No. 5, September-October 1977), and is reprinted here with permission from the publishers. Copyright 1977 by Rodale Press, Inc.

organic nitrogen compounds assimilable by algae are the simpler amino acids (e.g. glycine, alanine). In sewage, nitrogen is mostly organic or in the form of urea, although a significant amount may occur as ammonia. Consequently, to attain maximum removal of nitrogen from the water, it is necessary that the more complex nitrogenous compounds be broken down to forms utilizable by the algae. This is done by the bacterial component of the symbiosis. The algae also rely to a large extent upon the CO_2 resulting from bacterial metabolism for their carbon source.

The role of the algae in the arrangement is to provide oxygen, which is used by the bacteria to oxidize the wastes. The oxygen is a result of photosynthesis carried on by the algae. In photosynthesis, light energy in the visible range of the light spectrum serves as an energy source for the reductive synthesis of organic cell material from CO_2 coupled with the formation of molecular oxygen. The reaction may be represented as:

$$CO_2 + 2H_2O \xrightarrow{\text{Light}} (CH_2O) + H_2O + O_2$$

Oxygen production in algae production pond on a warm sunny day is so great as to result in supersaturation. In fact, we have observed oxygen concentrations as high as 35 mg/liter. Even in conventional stabilization ponds designed solely for wastewater treatment, photosynthetically produced oxygen constitutes the major portion of the dissolved oxygen in the ponds.

The removal of waste nutrients is not limited to nitrogen, it also includes others that can be assimilated by the plants. Thus, a certain amount of phosphorus, magnesium, and other metallic compounds are converted to algal protoplasm. Typically, however, the greater part of the total phosphorus removal is not due to assimilation by the algae. Rather it is the result of the conversion of phosphorus to insoluble compounds. The conversion is accelerated by certain changes in the physical-chemical conditions in the pond that result from algal growth. The major change is a drastic rise in pH level, probably due to the extensive utilization of CO_2 by the algae. Algae also have the capacity of concentrating non-nutritive compounds either by assimilation or through adsorption. For example, studies at the laboratory have shown that they concentrate DDT and its derivatives, even radioactive strontium, and an assortment of heavy metals. This ability could be a disadvantage when algae are raised to be a feedstuff. The solution is to see to it that such substances are excluded from domestic wastewaters.

It is essential that the algae be removed from the reclaimed water. Otherwise they eventually would die and through their decomposition products recontaminate the waste. The degree of importance is a function of the algae concentration and of the intended use or destination of the reclaimed water. If the water is intended for irrigation, the algae need not be removed, and in fact would enrich the soil with nitrogen. On the other hand, if the destination is a lake, practically all of the algae should be removed.

(b) *Pond types.* The number of types of treatment ponds is legion. For our purposes we shall concentrate on two types, namely, facultative ("oxidation", "conventional stabilization") and algae production ("high-rate"). The facultative pond is designed primarily for waste-water treatment, and algal growth is kept to the minimum needed to accomplish treatment. On the other hand, as the name implies, an algae production pond is designed with the goal of maximum production of algae, although economics make it imperative that waste-water treatment be given a position of equal importance. The types differ in other important respects: A facultative pond incorporates both anaerobic and aerobic decomposition, i.e. anaerobic in the lower strata and aerobic in the upper (illuminated) strata. Algae productions ponds are aerobic throughout. The retention time with a facultative pond is much longer, i.e. about 30 days; whereas it is only about four days with an algal production pond. However, respective advantages and disadvantages of detention time are counterbalanced by difference in depth, in that the optimum depth for a facultative pond is from 8 to 10 ft (2.4 to 3 m), whereas for an algae production pond, it is only 9 to 14 in (23 to 37 cm).

In choosing between types, a facultative pond would be indicated for a situation in which a simple, inexpensive treatment system is the major concern and land is not unduly expensive. However, if land is fairly costly, and if the goal is maximum conservation, i.e. both of water and of waste nutrients, then the algae production pond is the one of choice. Because of special design features, it is more expensive to construct and operate than a facultative pond.

Because time does not permit a detailed description of the design features of both types, this presentation proceeds directly to a short discussion of the advantages and disadvantages of both. Probably the major disadvantage of the two types is the large land required. On the average, about an acre (0.4 ha) of facultative pond area is required to satisfactorily treat the wastewaters of 200 people. With an algal production pond, the wastewaters from 1,000 people could be treated per acre. A second disadvantage for both is that they are heavily dependent upon climatic conditions, in that they function best under warm, sunny conditions. Of the two, the facultative pond is the less sensitive. A major advantage of the two is that if the algae are harvested, then secondary and tertiary treatment are accomplished simultaneously. The major advantage of the algae production type is that a very useful feedstuff is produced. Animal feed tests have shown that the algae product usually is from 40 to 50 per cent protein and can substitute for soybean oil meal and to some extent even for fishmeal. Depending upon climatic conditions, yields range from 20 tons (dry weight)

per acre (60 metric tons/ha) to as high as 40 to 50 tons per acre (120 to 150 metric tons/ha) per year. Thus an algae production not only is a treatment device, it also is a highly productive agricultural system.

Lest the reader be overwhelmed by the glowing narration of the potential of the algae production pond, we hasten to add that there is a serious obstacle to be overcome before the potential can be realized. This obstacle is the harvesting of the algae. As of now, no completely satisfactory harvesting method is available. The difficulty arises from the microscopic size and the low specific gravity (almost that of water) of the algal cell. However, research on one or two promising concepts is underway at the University of California, and chances are that in a year or two a satisfactory solution to the harvest problem may be found.

Vascular plant systems

The information presented in this section was obtained in great part from several publications.[2] While there are many other worthwhile papers on the nutrient removal by vascular plants, the references cited happened to be available to the writer at the time of the composition of this paper.

(a) *Submerged plant method:* Although submerged aquatic weeds can assimilate and thus remove nutrients from wastewaters, they grow well only in oxygenated waters. Consequently, they are not suitable for treating raw sewage or other wastewaters that have a high organic content. The reason is that the intensive microbial activity which ensures that the decomposition of the organic wastes results in an oxygen demand so great that all of the available dissolved oxygen is soon depleted, and as a result anaerobic conditions prevail. Submerged aquatic weeds perhaps would be suitable in tertiary treatment. At this stage bacterial activity is at a minimum, and soluble inorganic conversion products are the major class of substances remaining to be removed.

Because they are submerged, underwater weeds are difficult to harvest mechanically. Therefore, the best means of harvesting them is through the culture of aquatic herbivores. If this is done, the stocking rates of the herbivores must be carefully balanced lest the weeds be overharvested, and the over-all nutrient removal capacity of the system be thereby reduced.

Submerged weeds would be useful in the final or "polishing" pond of a series of conventional stabilization ponds. This writer has observed one such series, which consisted of four successive lagoons, the fourth of which was the "polishing" pond. The fourth pond supported an abundant growth of elodea and other assorted submerged plants, as well as a wide variety of animal groups ranging from crayfish and frogs to fish. Despite the fact that raw sewage was fed into the first pond (almost completely anaerobic) of the series, the effluent from the final pond was sparkling clear, had a BOD at the lower limit of detection, and a coliform MPN of only 1 per 100ml.

(b) *Floating plant method.* Floating plants proposed for wastewater treatment generally are members of the group known as "duckweeds" *(Lemnaceae)*. Technically, water hyacinths could perhaps be placed in this group, since the plants do float upon the water. However, because of the wide disparity between the large size of the water hyacinths and the minuteness of the duckweeds as well as of other differences, the water hyacinths are placed in a class by themselves. Despite their minute size, a few centimeters at the most, duckweeds are complete vascular plants that float upon the water surface. Representative genera of the duckweeds considered for wastewater treatment are *Wolfia*, *Spirodella*, and *Lemna*.

The concept of using duckweeds for the removal of nutrients from wastewaters is not novel. In the 1960s when research on the development of long-term life support systems in space was almost as heavily funded as is energy research at present, duckweeds were proposed as an alternative to algae systems for photosynthetic life support systems.[3]

Because of their exponential growth rate, colonies of duckweeds can absorb considerable quantities of nutrients. Doubling time ranges from 3 to 7 days in lagoons during the growing season in the southern tier of states. Growing at this rate on a 1-ha (2.471 acres) lagoon, *Spirodella oligorhiza* will remove the nitrogen, phosphorus, and potassium of 207 dairy cows occupying a milking parlor four hours per day and fed standard United States rations. Monthly yields range from 1.7 to 6.7 tons (dry weight)/ha (0.69 to 2.7 tons/acre). The crude protein content approaches 40 per cent on a dry weight basis.

The floating plants are easy to harvest by skimming the surface with a rake or net. An arrangement being tested in Louisiana is one in which the plants are

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[2] *Making Aquatic Weeds Useful: Some Perspectives for Developing Countries.* National Academy of Sciences (Washington, D.C., 1976), pp. 115-126; D.A. Cornwall, J. Zoltek, Jr., C.D. Patrinely, T.de S. Furman and J.I. Kim, "Nutrient removal by water hyacinths", *Journ. Water Pollution Control Fed.*, 49(1): 57-66 (Jan. 1977); E. Scambrook and D.E. Davis, "Effect of sewage on growth of five vascular aquatic species", *Hyacinth Control Jour.*, 9:26-30(1971); E.S. del Fosse, "Waterhyacinth biomass yield potential" (published copy has no identification as to place or occasion of presentation; Del Fosse is research entomologist, Lee County Hyacinth Control Dist., Route One, Fort Myers, Forida 33905; the paper was written either in 1975 or 1976); D.D. Culley, Jr. and E.A. Epps, "Use of duckweed for water treatment and animal feed", *Journ. Water Pollution Control Fed.*, 45(2):337-347 (Feb. 1975); D.L. Sutton and W.H. Ornes, "phosphorus removal from static sewage effluent using duckweed", *Journ. Environmental Quality*, 4:367-370 (1975).

[3] C.G. Golueke, "Role of plants in closed systems", *Annual Review of Plant Physiology*, 15:367-408 (1964).

floated off the surface of a pond into perforated troughs that drain away the water. Livestock can eat the plants directly out of the trough.

While a duckweed culture system may seem attractive, its use is attended with many serious difficulties. The floating colonies are easily broken up by wind action, and then eventually accumulate and form decaying mats along the banks of the lagoon. Year-round growth is limited to tropical regions. The high moisture content (90 to 95 per cent) of the plants makes handling and transport in large quantities difficult and expensive. Moreover, some members of *Lemna* contain oxalic acid, which would limit their use in animal feeds.

(c) *Emergent plant methods.* Reeds and bulrushes are the plants used in emergent plant methods. The untreated waste water is first passed through a bed of gravel topped with sand in which common reed is planted. After the reeds have grown 6 to 13 ft (2 to 5 m) tall and their roots have spread through the sand, waste water is spread over the surface of the bed. Solid particles are filtered out by the sand as the water percolates downward. Dissolved organic and inorganic matter are absorbed by the weeds or are broken down by microorganisms in the gravel. The oxygen needs of the microorganisms are met by the transport of air through the air passages characteristically in the stems of reed plants. As the sludge accumulates on the surface of the bed, the reeds send new roots into it from along the base of their stems. The roots take part in the digestion of the sludge and thus retard buildup of the sludge layer.

In the second stage of the process, the effluent from the first stage is passed over a gently sloping bed of gravel planted with bulrush. Additional organic materials and inorganic nutrients are removed by the plants. Colloidal substances in the water flocculate and settle out. A significant reduction in pathogen number results. The final effluent is clear, has a pH of 7, and has a very low BOD, but it may contain some dissolved phosphorus and nitrogen. The reeds and bulrushes are harvested periodically.

(d) *Water hyacinth method:* At present, of the vascular plant methods the water hyacinth is receiving the most attention. The extremely vigorous growth of the plant appears to a number of researchers to offer the potential of a correspondingly effective removal of nutrients from waste-waters. Among the several studies on the wastewater treatment potential of water hyacinth systems is an investigation mentioned in the National Academy report as being conducted by the National Space Technology Laboratories (U.S. Government facility operated by the National Aeronautics and Space Administration). The project involves the "farming" of water hyacinths on an 8.9-acre (3.6-ha) sewage lagoon serving the city of Lucedale, Mississippi (population 2,500). Other studies mentioned in the report are those being conducted by the University of Florida and the Texas State Department of Health Resources. Results obtained in the studies indicate that in the subtropical climate of Florida, Mississippi, and Texas, water hyacinths can increase at a rate of 15 per cent surface area/day. At such a growth rate, from 20 to 40 tons of wet water hyacinth (90 to 95 per cent moisture content) could be harvested per hectare per day (8 to 16 tons/acre/day). A mass of weeds of this magnitude would account for the removal of nitrogen in the wastes from 2,000 people and the phosphorus in the wastes from 800 people or more. The amount of nutrients removed under ideal conditions is indicated by the data in table 1, which was taken from the National Academy report.

Table 1. Nutrient removal by water hyacinths

Element	*Amount recovered (kg/ha/day)*
nitrogen	22 to 24
phosphorus	8 to 17
potassium	22 to 24
calcium	11 to 22
magnesium	2 to 4
sodium	18 to 34

In the Florida study it was found that water hyacinths double in area every 6 to 7 days during the growing season (March to November). Approximately 80 per cent of the nitrogen and 40 per cent of the phosphorus was removed in two days from sewage passed through a pond at 2.2 million l/ha/day. Reportedly, algae and fecal bacteria are removed in water hyacinth systems, as are odor-causing compounds and other undesirable substances. Part of the removal must be attributed to the zooplankton growing in the shelter of the plants.

Harvesting the water hyacinth crop poses some difficulties that remain to be solved. A problem arises from the fact that the plants are growing in an aquatic medium, and hence the harvesting equipment must be on some type of boat or raft. Propelling any craft through the tangled mass of hyacinths is where the real difficulty comes in. Another difficulty is the rapid clogging of the harvesting mechanism (chopper or sickle blades, for example). The hyacinth crop must be dewatered before being fed to livestock. The reason becomes apparent when one considers that if the wet plants were fed to an animal, it would have to excrete 95 kg of water for every 100 kg of hyacinth eaten. Dewatering is not easily accomplished, and research is being conducted on the development of an effective system. Another drawback is that the method is limited to subtropical and tropical regions.

Finally, a cautionary note is in order: The plant should not be introduced into regions where it is not al-

ready found. It is notoriously prolific weed and can cause untold damage to waterways if allowed to escape – an event that would be highly probable.

Relative advantages of algal and vascular plant systems

Four factors are of major concern in comparing the utility of algal systems with that of vascular plant systems: (a) ease of manipulation (management), (b) efficiency of treatment, (c) ease of harvesting the plant crop, and (d) utility of the crop.

Because of the minute size of the plants, algal systems are more amenable to automation than are macroscopic systems. Algal suspensions can be manipulated hydraulically as if they were devoid of plants. Thus flow rates and transfer equipment and procedures are identical with those for water alone and with the same degree of predictability. With higher plant systems, operational procedures involve two instead of one control system, one for the plants and a second for the liquid phase because both must be managed separately. Efficiency of treatment is manifested by quality of treatment attained, ease of attaining it, and in this case, water and crop yields per unit of pond area (i.e. land use). Generally the quality of the reclaimed water with both types is comparable. Ease of attaining the quality seems to be in cause the algae are dispersed throughout the water medium, and because of its morphology (no roots, etc.), the entire algal cell is active in assimilating nutrients. Because of their microscopic size, the surface to volume ration of algae far exceeds that of higher plants. In the treatment process, surface area is of prime significance. Inasmuch as rate of nutrient removal is a function of rate and amount of plant growth, algal systems would surpass higher plant systems in this respect because of the exceedingly rapid growth of unicellular algae. In terms of treatment, algal systems are more efficient because they are readily operated as continuous systems, i.e. with a continuous inflow and outflow. Many of the higher plant systems involve batch treatment, with an attendant drop in efficiency of equipment and land use.

The factor of relative ease of harvesting has room for debate. As stated earlier, harvesting constitutes a major difficulty with algal systems. On the other hand, one would think that because of the large size of the plants, the vascular plant crop could easily be harvested. Experience has proven otherwise. The difficulty is due to the fact that the only access to the plants is by way of water, in other words harvesting equipment must be waterborne. While floating may not be hard to achieve, as stated earlier, propelling the float and its burden of equipment through a mass of aquatic weeds is a far from easy task. Even with emergent systems, harvesting must be done occasionally, otherwise the accumulation of dead and decaying vegetative matter would soon clog the system.

Lastly, it should be pointed out that the algal crop, once it has been harvested and processed, constitutes high quality feedstuff. The same probably could be said of the water hyacinth and duckweed crops, although the protein content of the algal product is considerably higher.

Of the three groups of plants (algae, hyacinth, and duckweed), algae probably would be the most readily adaptable to uses other than as a feedstuff. Thus, in situations in which the algal crop is to be used as a fertilizer, and the treated water for irrigation, the algae can be left in the effluent. If applied separately and storage of the algal crop longer than a few days is involved, the algal product must be dried, otherwise it will decompose to the accompaniment of horrendous stenches. The same conditions apply to duckweeds. Water hyacinths would have to be removed and preferably composted before application to the soil. If methane fermentation is the aim, algal and duckweed crops need no preparation other than some concentration. Water hyacinths would have to be chopped to a fine particle size. Methane yield would be about the same from all three crops.

Purification for personal use ...

at home...: an innovative device that treats water with an electromagnetic field has been patented by Miguel F. Brigante of Miami, Florida,, USA. Patent No. 4,288,323 describes the equipment as a conduit pipe surrounded by a coil that induces a magnetic field within the pipe. Inside the pipe is a shaft with a rapid impeller close to the walls to sweep away particles. A filter is also included. The equipment is under consideration for use to remove toxic copper waste near mines in Chile and for purifying river water in Nigeria. In the home, the device can be attached to a water heater or boiler. The home size device, described as long lasting, is marketed under the trademark "Electromag". The inventor is reported to have previously developed purification equipment to clean industrial waste from water from paper mills, electrical plants and insecticide factories.

SOURCE: *Water Newsletter*, WIC, 30 September 1981

... or at sea. Two Navy engineers say they have DEVELOPED A PORTABLE AND LESS EXPENSIVE METHOD OF CHANGING SALT WATER INTO FRESH WATER. Wayne Adamson and Joseph Pizzino of the Taylor Naval Ship Research and Development Center say the device produces fresh water at the rate of about 1¼ gallons per hour, costs about $500, and can be stowed on life boats. Called a reverse osmosis desalinator, it filters the sea water through cellophane that separates the salt from the water. Other machines do the same thing, but none are as small (2 feet long) or as proficient (30 gallons a day), according to the engineers. Experts say a person needs a gallon of water a day to survive on the open sea. Current desalinators do not meet this requirement, and navy lifeboats can store only about 1½ quarts of water per passenger.

SOURCE: *Water Resources Bulletin*, AWRA, February 1981

ASIAN AND PACIFIC EXPERIENCE

STORAGE RESERVOIRS IN INDIA

C.C. Patel[1]

Water is the most precious gift of nature to India. Its most beneficial use is a *sine qua non* not only for economic development but also for meeting the growing food requirements of the country. Rainfall in the country is confined to 90 to 100 days of monsoon season, and is unevenly distributed both in space and time even during the monsoon season. Increased numbers of storage reservoirs are, therefore, essential to achieve high degree of water utilization for various purposes. Agricultural production needs to be more than doubled in the coming two decades or so, and most of it has to come from more efficient land and water management in existing irrigated areas, and extended irrigation in new areas. There is hardly any scope to increase the cultivated area. Conservation and utilization of water resources for beneficial uses such as irrigation, hydropower, flood control, water supply, navigation and other purposes through storage reservoirs and water transfer systems will also provide large-scale additional employment opportunities to several millions living in the rural areas.

Rainfall

The mean annual rainfall of India has been estimated to be 117 cm. However, almost 85 to 90 per cent of this rainfall is received only in the four months of June to October of the south-west monsoon period. The balance precipitation occurs during the north-east monsoon period of November and December, only in the coastal belts of Tamil Nadu, Andhra Pradesh and parts of Orissa. Over most of India, therefore, successful raising of only one crop is possible in the *kharif* season. Even in this season, there are considerable variations, not only in the quantum of rainfall from year to year, but also in its distribution during the rainy period of four months, in its incidence, dates of onset and withdrawal. Further, on account of the very large variations in the topographic and orographic features of the country, the average annual rainfall in different parts varies considerably. For example, while a portion of the Western Ghats, the whole of the Khasi Hills and parts of Brahmaputra Valley receive more than 250 cm of rainfall, the maximum rainfall being as high as 1,140 cm, the annual rainfall is as low as 17 cm in some parts of Rajasthan. The southern slopes of the Himalayas and the east coast extending from Madras to Calcutta and also hills of Bihar, Orissa and Madhya Pradesh receive generally over 100 cm.

Analysis of the available rainfall data over more than a century indicates that the coefficient of variation of the rainfall from year to year is about 30 per cent over large areas of the country, and over 40 to 50 per cent in parts of Saurashtra, Rajasthan etc. In some of the interior districts in these areas, as well as in the Deccan Plateau, the variability is as high as 100 per cent or more, with very heavy rainfall during some years and very little rainfall during other years. It has been roughly estimated that not less than one third of the country is subjected to chronic drought conditions. A further characteristic is the flood/drought/flood syndrome. Sometimes, the floods and droughts occur during the same year in the same area.

Large tracts of the country, particularly the Ganga and the Brahmaputra basins, are liable to receive excessive rainfall concentrated in a short period through heavy downpours caused by cyclones, storms and depressions. Heavy rainfall of the order of 25 to 30 cm in a day has been recorded at a number of places. In Gujarat and Rajasthan, some places receive the annual normal rainfall in one day. Dharampur in Surat district, a plain station, for instance recorded 100 cm on 2 July 1941. In 1977, the desert districts of Rajasthan, which receive an average annual rainfall of only 25 cm, received as much as 50 cm in a period of two or three days. Floods are many times followed by drought, affecting the yields of crops which have survived the floods.

Characteristics of river flows in India

Among the various rivers in the country, there are five rivers which have a peak discharge of more than 42,860 m^3/sec. These are the Godavari with maximum discharge of 88,600 m^3/sec, followed by the Brahmaputra with 74,300 m^3/sec, the Ganga and the Naramada with about 71,400 m^3/sec, and the Mahanadi with a discharge of about 45,000 m^3/sec. These five river systems together drain an area of 2.3 million km^2 which is roughly 75 per cent of the total area of the country. Out of the various river systems, the Ganga and the Brahmaputra systems together carry more than 60 per cent of the total flows.

The seasonal nature of rainfall in India is reflected in the river flows. In the monsoons, the heavy rainfall

1 Secretary, Department of Irrigation, Ministry of Agriculture and Irrigation, New Delhi. This article was originally published in *Irrigation and Power* (vol. 36, No. 4, October 1979), the official journal of the Central Board of Irrigation and Power of India, and is reprinted here with their permission.

results in high flows and damaging floods, while in the winter and summer, even the major river systems of the peninsula dwindle down to very low flows. The monsoon flows in the central Indian and peninsular rivers thus amount to more than 90 per cent of the annual flows. The Indus, Ganga and Brahmaputra, however have some snow-fed catchments in the Himalayas but even in their case, the monsoon flows between June and October account to over 80 per cent of the total annual flows. Owing to the characteristics of the monsoon, there are also large variations in the annual flows of the rivers, particularly, in the central Indian and peninsular rivers[2]. Thus, the Narmada at Gardeshwar has an average runoff of 50.6 billion m^3 based on a 1891 to 1970 series. Against this, the runoff during the year 1899/1900 was only 5.9 billion m^3, while 1961/62 had a runoff of 75.6 billion m^3.

In comparison, the average observed annual flow of the Ganga at Farakka over the last 30 years is about 396 billion m^3, ranging from a minimum of about 239.5 billion m^3 in 1972/73 to a maximum of about 554.2 billion m^3 in 1971/72.

The variation of daily river flows over the year is also extreme. The Narmada has a flow of only 29 m^3/sec in summer, against a maximum high flood of 71,400 m^3/sec. The Ganga has a minimum overflow of about 1,100 m^3/sec, and a peak maximum of 71,400 m^3/sec. The Brahmaputra has a minimum flow of 2,857 m^3/sec, compared to a maximum of 73,370 m^3/sec. Several major tributaries, particularly in the rain-fed rivers, have extremely large flows in the monsoon and are bone dry in summer.

Pre-independence development

The need for utilizing the waters for irrigation has been recognized in India from prehistoric times. There are innumerable wells all over the country and a number of tanks (small storages), some of which are over 1,000 years old, particularly in Andhra Pradesh, Tamil Nadu and in parts of Rajasthan. Except for the Grand Anicut across the Cauvery constructed in the second century, there is however, not much evidence of major structures across large rivers for harnessing the surface flows in the historical past.

With the passage of time, irrigation went on developing. However, large areas developed under irrigation by utilization of the perennial flows by diversion in the northern rivers of the country, as they provided favourable conditions for diverting such flows through the canals. The most notable and almost pioneering work of this nature was the construction of Western Yamuna Canal in 1355. Subsequently, the Eastern Yamuna Canal was constructed in the eighteenth century. Both these canal systems are even now irrigating vast stretches of land in Haryana and Uttar Pradesh.

In the early part of the British period, attempts were directed towards improvements of the existing works, namely the Cauvery Delta System in the south, and the Western and Eastern Yamuna Canals in the north. The success of these works and the protection afforded by them against scarcity conditions led to further works of this type in the form of Upper Ganga Canal in Uttar Pradesh, Uppder Bari Doab Canal in the Punjab, and the Godavari and Krishna Delta projects in Andhra Pradesh. These were followed by Sirhind Canal in Punjab, Lower Ganga Canal, Agra Canal, among others in Uttar Pradesh. It is worth noting that all these works involved diversion structures utilizing run-of-the-river flows. Except for Khadakwasala Dam constructed in 1887, no significant storages were constructed during the nineteenth century. Even in the beginning of the twentieth century, only a few storage reservoirs were constructed across the Godavari and its tributaries in the State of Maharashtra, followed by Krishnarajasagar Dam in Mysore, Nizamsagar Dam in Andhra Pradesh and the Mettur Dam in Tamil Nadu.

By independence, there were about 190 storage reservoirs, few of them of significant size, with a total effective capacity of about 12.3 billion m^3. Only about 30 dams were more than 30 m high. The dams were confined to the peninsular area and were low earth dams, or hand-built masonry dams.

At the time of independence about 19.7 per cent of the net cultivated area was being irrigated. The distribution was as follows:

Source	*millions of ha*
Government canals	6.3
Private canals	1.9
Wells	5.3
Tanks	3.3
Other sources	2.6

Out of the irrigation through the Government canals as much as 5.76 million ha was irrigated by diversion schemes, while storages accounted for only 0.58 million ha. In addition, tanks on local streams formed a significant source of irrigation specially in the peninsular areas, where the density of tanks was sometimes 0.4/km^2. Formed by small earthen bunds, these ponds fill up two or three times in the rainy season and redistribute to some extent the available supplies and tide over "breaks" in the monsoon. Even though they are susceptible to the vagaries of rainfall, they have played and continued to play an important role in the irrigated agriculture in the Indian peninsular areas.

2 The following figures for flows are quoted in billions, or thousands of millions.

Post-independence development

In the 1930s there was a spurt in construction of large dams, mainly by mechanized equipment in the advanced countries, particularly in the United States of America. In the years following the Second World War, the post-war reconstruction programme initially, and the post-independence programme subsequently, gave a real fillip to storage projects in India. Major storage structures like the Bhakra Dam on the Sutlej, the Hirakud Dam on the Mahanadi, four dams on the Damodar and Tungabhadra Dam on the Tungabhadra were taken up as part of post-war reconstruction programmes, and an expenditure of about Rs. 800 million incurred on them prior to 1951. National plans for development initiated in 1951, progressively included storage schemes not only for irrigation but also for such other benefits as power, flood control and navigation. During the five-year plans, an investment of the order of Rs. 54,540 million has so far been made on major and medium irrigation. Over 640 new dams including 110 of height 30 m or more were taken up and completed. Notable among these are the Rihand, Ukai, Koyna, Iddiki, Ramganga, Tenughat, Sharavathi, Balimela, Gandhisagar, Nagarjunasagar, and Rana Pratap Sagar. The effective storage has been raised to about 134 billion m^3. The irrigation potential in the country in 1978 was broadly assessed to be 52 million ha, as indicated at the top of the next column.

Scale of schemes	*million ha*
Major and medium schemes	24.77
Minor schemes:	
surface water	7.50
ground water	19.80

The accompanying table shows the average flows in the various basins in the monsoon and non-monsoon seasons, and the effective storages and irrigation potential from major and medium schemes in 1947 and 1978. From the table, the major and medium irrigation projects have registered an increase of 15 million ha in irrigation potential. The bulk of the increase is storage schemes, since only about 2 million ha of the increase has resulted from new diversion schemes.

The installed hydroelectric capacity in India was 500 MW at the time of independence, and 2,194 million kWh were generated. The installed hydro capacity now is about 11,000 MW, and the generation is 47,000 million kWh. Most of the increase in hydroelectric capacity has come from the undertaking of storage-backed, multi-purpose projects. A number of projects are presently in progress which will add a further installed capacity of 4,000 MW during the current plan period.

Name of basin	*Average flow in billion m^3*			*Major and medium projects up to 1947*		*Major and medium projects up to 1978*	
	Monsoonal	*Non-monsoonal*	*Annual*	*Live storages (m^3) (billion m^3)*	*Irrigation potential (1 000 ha)*	*Live storages (m^3) (billion m^3)*	*Irrigation potential (1 000 ha)*
Indus (available to India)	37.90	6.89	44.79	–	1 514	14.69	4 078
Ganga	331.57	58.90	390.47	1 02	3 969	30.71	11 641
Brahmaputra, Barak	556.79	160.60	717.39	–	–	0.14	83
Godavari	575.98	60.00 (approx.)	118.98	1.69	1 037	15.32	1 675
Krishna			68.23	3.11	946	30.63	2 116
Cauvery			20.70	4.12	1 004	7.17	1 157
Small east-flowing rivers–Mahanadi to Pennar, incl. Pennar			23.81	0.09	282	0.59	453
Small east-flowing rivers–Pennar to Kanyakumari			17.73	0.28	186	1.31	239
Mahanadi			66.88	0.58	413	6.58	1 269
Brahmani, Baitarni			36.23	–	60	0.62	156
Subarnarekha			10.76	–	5	0.60	10
Sabarmati			2.88		19	1.10	153
Mahi			1.83	0.52	9	2.86	250
West-flowing rivers of Kathiawar, Kutch, Luni			15.10	0.13	26	2.31	222
Narmada			42.97	0.04	7	2.66	163
Tapi			16.97	0.05	35	7.67	538
West-flowing rivers from Tadri to Tapi			110.88	0.17	–	0.33	17
West-flowing rivers from Capecomerin to Tadri			71.98	0.53	188	9.02	550
Totals	1 502.24	286.39	1 788.63	12.33	9 700	134.31	24 770

The dramatic effects of storage in harnessing the country's water resources are evidenced by the fact that in the Ravi, Beas and Sutlej, hardly 9.9 billion m^3 was being used before independence. With the construction of the Bhakra, Pandoh and Pong Dams, it is now possible to use 38.3 billion m^3. When the Thein Dam is in position, the utilization will rise to 40.7 billion m^3.

In the Krishna and Cauvery deltas, hardly 20,000 ha of second crop was possible in the past. With the construction of storages, over 250,000 ha of second crop are now grown in each of these deltas, apart from bringing irrigation in extensive areas elsewhere in the basins. The storage have also been invaluable in flood control. The Bhakra Dam in 1978 was able to moderate a peak flow of about 11,320 m^3/sec to 2,830 m^3/sec below the dam. The Damodar Valley reservoirs too, in 1978, moderated an incoming flood peak of 21,225 m^3/sec to 3,820 m^3/sec. The case for the Ukai and Chambal Dams is the same.

Indigenous expertise built up

In the 1950s, while the medium projects were capable of being built by the techniques with which Indian engineers were already familiar, foreign assistance was necessary in the planning, design and construction of large masonry and earthen dams, such as the Bhakra, Rihand, Hirakud and Damodar. Indigenous expertise was simultaneously developed and soon the country became self-reliant. Early in the 1960s, the country could develop its expertise at national and state levels for large water development programmes envisaging large storages, high dams of various types, and vast networks of big and small canals. Currently there are in the country various types of dams--earth, rockfill, masonry, concrete, composite, gravity and arch. India in 1979 has the longest earth dam in the world, namely the Hirakud; the highest masonry dam in the world, the Nagarjunasagar; and one of the highest concrete gravity dams, in Bhakra. The Pong Dam on the Beas River and the Ramganga in Uttar Pradesh are examples of earth-rock-fill dams in difficult terrain, in seismic areas. The Idikki Dam in Kerala is the first arch dam in India of double curvature, 117 m high. In the construction of these dams and the connected works, a number of complex problems in foundations, tunnelling, river diversion and other aspects arose which were tackled successfully by the Indian engineers with some assistance from abroad. Tehri Dam, a rockfill type 260.5 m high, is under construction. Progressively most of the equipment needed for the construction of projects is also being manufactured locally, eliminating such difficult problems as foreign exchange purchases and availability of spare parts.

Perspective of development

Out of the total 328.778 million ha of its geographical area, about 66.435 million ha are forested, 39.519 million ha are under non-agricultural uses or are barren, and 34.165 million ha are pastures or orchards. The cultivable land in the country is thus about 188.659 million ha. The net area planted in 1975/76 was about 142.224 million ha, and the total cropped area was about 170.995 million ha.

The Irrigation Commission and National Commission on Agriculture have broadly assessed the utilizable surface-water resources of the country at 700 billion m^3, representing about 39.1 per cent of the average river flows in the country. Broad assessments have shown that if the rivers are developed on the basis of local requirements and availabilities, the eventual irrigation potential from major and medium projects would be about 58.5 million ha. Compared with other countries, the possibilities of large storages in India are limited. In the United States, for instance in 1974, there were 8,000 dams with a gross storage capacity of 1,053 billion m^3.

While conjunctive use of surface and ground water in India may provide some additional supplies, this too has its own limitations. Underground storage of flood waters has not been attempted on any large scale in the world. Ground-water pumping in preference to use of surface water involves high costs and requires considerable energy. Widespread reduction of the ground-water table may have varied ecological and environmental effects. There may be sharp reduction in the evapotranspiration, affecting vegetation, trees, forests and crops. Channels and rivers which carry fair-weather flows used for domestic, industrial and irrigation supplies may dry up. Hundreds of thousands of low-lift pumps already installed may be rendered infructuous by substantial reduction of the ground-water table. There would be possibilities of increased pollution both in the surface and underground water environments, and settlement and subsidence of the ground. There may be delineation of aquifers according to settlement. It is therefore necessary to exploit to the maximum extent, where technically and economically practicable, the available storage sites for surface water for direct use as well as for recharge. Given the monsoon characteristics of river flows, the storage of flood waters in India is of supreme importance in increasing water-use opportunities.

The development of the potential of the various rivers in order to compensate for the shortages of other rivers would also have to be carefully taken into account. The possibilities of storage for hydroelectric generation at favourable sites, even though dams may not be needed there for regulation of the flows farther downstream, would also have to be exploited. Broad assessments show that in a broad perspective of water resources development, including the harnessing of rivers in co-operation with neighbouring countries, it may be possible to augment the irrigation potential in India from major and medium projects to about 83 million ha. The broad assessment of the total storage capacity of the various river systems is about 425

billion m^3. With this development, the ground-water potential in the country may be about 45 million ha, and the minor surface irrigation potential about 20 million ha, bringing the total potential to about 148 million ha. That would be about 70 per cent of the eventual gross cropped area of 210 million ha.

Reservoirs involve in many cases displacement and dislocation of people and interests. A very liberal policy would, therefore, have to be evolved for mitigating the difficulties of the displaced population, not only by financial compensation, but also by providing alternative means of livelihood by reclaiming land, by providing employment opportunities on the project construction, operation and maintenance, and, to the extent feasible, by resettling in the command area. Rehabilitation policies should be aimed at improving the economic lot of the affected persons.

The key to higher agricultural production in India lies in increasing the irrigated area, and in improving the quality of irrigation. The rivers are monsoon-fed, and 80 per cent to 90 per cent of the flows occurs during the monsoons. Man-made activities have been aggravating the pattern of water flows by considerable deforestation; floods have been on the increase on many rivers, and the fair-weather flows have been on the decrease owing to the reduction in the natural water-holding capacity of the soil in the eroded areas. The only way to render the abundant waters utilizable is by means of conservation and storage.

Surface storages are economically very attractive and lend themselves to multipurpose benefits. They need to be looked into from the point of view of optimum planning in the context of the regional, national and, where appropriate, subcontinental needs. Water resources of such large rivers as Meghna, Mahanadi and Godavari, which carry surplus waters causing floods, do not realize their optimum value if the benefits of the development are confined within narrow boundaries. Exploitation schemes become economically viable with multipurpose development, devastating floods are controlled, and larger benefits are realized by all concerned at cost. Water is the only major resource available for development to give a fillip to the developing economy of the subcontinent, which is among the poorest regions in the world yet holds the potential to become a granary for the whole world.

The over-all plan of development of water resources has to be comprehensive, envisaging multi-purpose and multiobjective planning and development of waters for the greatest good of the largest number, keeping in view *inter alia* the benefits of irrigation, land reclamation, flood control, drainage and anti-waterlogging, river erosion control, hydropower generation, navigation, pollution control, recreation, fisheries, domestic and industrial uses of water. It has to take into account the appropriate socio-economic and environmental policies, and as well conjunctive use of ground and surface waters. Afforestation, soil conservation and other catchment-protection measures would also have to be an integral part of the development in order to preserve and enhance the environment and augment the life of reservoirs. It has to be energy-economic, and afforestation should be promoted around the reservoirs and elsewhere. It should aim at maximum possible exploitation of available hydropower sources, and the power installations should be such as to meet the peaking needs of power grids to the maximum extent, and enable economic exploitation of secondary power during monsoons. Regional imbalances in water availability must be removed to the maximum extent possible, and maximum production per unit of water aimed at.

Good dam sites are few in number in the world, and specially so in the Indian subcontinent. Those which are available have therefore to be harnessed optimally and their potential fully utilized within the framework of appropriate development-oriented policies.

THAILAND PLANS FOR INCREASING DEMAND*

When the Government removed its subsidy on oil, the Electricity Generating Authority of Thailand was faced with a rapid increase in generating costs. An urgent programme is under way to exploit the country's hydro resources quickly and effectively, and thereby reduce dependence on oil.

The rapid development of hydroelectric resources is of paramount importance to Thailand. It may, in fact, be the only way out of the vicious circle the south-east Asian country has been trapped in since the advent of the oil crisis ... [In March 1980] the Thai Cabinet announced that it could no longer carry out subsidizing the oil expenses of the Electricity Generating Authority of Thailand (EGAT), the central authority set up in 1969, at the rate of 337 million baht per month ($US 30 million) from its own resources because – apart from the crippling drain on the Royal Treasury – it felt it had been unfairly giving priority to electricity users at the expense of thousands of villages in remote

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areas which had yet to be provided with electricity. It ordered EGAT, which had already received 2 million baht in subsidies, to find a solution of its own– or, effectively, to muddle through as best as it could.

EGAT immediately raised its rates on a rising scale, aiming to get extra cash from those who could best afford to pay, which hit manufacturing industries the hardest, making them pay up to 50 per cent more for their electricity. The move was part of the country's general inflationary trend, which makes even optimistic analysts predict a 15-per cent rate of inflation for 1980, causing a decline of farm output and industrial growth.

But, worse still, the government's cutoff of subsidies caused a harrowing short-term problem, too. EGAT, which had been burning 10×10^6 l of bunker oil a day had to put a stop to its oil imports, for the time being at least.

To avert panic, the president of the utility company, Kasem Chatikavanij declared that–while EGAT would be stepping up its efforts to obtain more bunker oil–there was no immediate need for power blackouts, because the company had enough oil in store to continue generation "at more or less the normal level". EGAT would, he said, continue to use up to 7×10^6 l of bunker oil per day, and try to make sure simultaneously that water stored behind dams for hydroelectric generation would last until the next rainy season.

The rainy season was, however, still almost three months away: Thailand has a hot dry season from March to June, followed by a hot rainy season till October and the south-western monsoon, and a cool dry season from November to February when the north-eastern monsoon comes. Extra bunker oil and thus money needed to be found.

Shortly afterwards EGAT declared that it would install a 500 kV cable–the first in high-voltage transmission not only in Thailand, but in all ASEAN countries–by 1986, spanning the 550 km stretch between Mae Moh generating plant in Lampang and a substation in the centre of Bangkok, and that this would represent a first step towards a high-voltage national grid, which was to be the long-term answer to an even electricity distribution throughout the country. It was also to be beneficial, EGAT claimed, in terms of oil consumption, because fewer circuits were needed and so less oil would have to be burned.

Mae Moh is the site of one of EGAT's two lignite mines in the province of Lampang: the other one is the Krabi mine in Krabi province. One is in the north, the other in the south of the country, and they were administered before the establishment of EGAT by the Lignite Authority (LA), which built lignite-fired generation plants in both locations, installing two 6250 kW units at Mae Moh in 1960 and three 20 MW units (two in 1964 and one at the start of 1969) at Krabi.

EGAT was formed from three regional authorities; the Yanhee Electricity Authority, which had been responsible for the generation and distribution of electricity in the central and part of the northern region, the North-East Electricity Authority (NEEA) and LA. It inherited a total generating capacity of 841.7 MW, which it increased to 2143.9 MW by the end of 1974 and roughly twice that figure now.

Apart from the two lignite-fired plants, EGAT also inherited one more steam powerplant and added a further two since, all of which are oil-based. The two 75 MW and one 87.5 MW units of the North Bangkok plant, on the banks of the Chao Phraya River, became operational in 1961, 1963 and 1968 respectively. The Surat Thani plant in the south came on stream with a single 30 MW unit in April 1973, and its capacity has been doubled since. And the South Bangkok plant, in Samut Prakan province and also on the Chao Phraya, had a 200 MW unit installed in 1970/71, a 300 MW unit in 1974, and has since that time been enlarged to 1300 MW with two further 300 MW generating units, so that today it is the largest steam power generating plant in the whole of south-east Asia.

High-rise demand

Between 1974 and 1978 oil-fired generation increased from 1040 MW to 1597.5 MW in Thailand, mainly to feed the voracious demand for power of the American-styled, air-conditioned, high-rise blocks in Bangkok.

EGAT also installed 23 diesel generators early in the 1970s at four plants–9 MW at Mae Moh, 10.6 MW at Phuket, 8 MW at Chiang Mai and 2 MW at Nakhon Si Thammarat–to boost peak power and regulate voltage levels especially in the dry seasons, and eleven 15 MW gas turbines. Two of the rapid-start units were installed at the North Bangkok plant and four at the South Bangkok plant. Five further units went to substations at Bangkapi, Nakhon Ratchasima, Udon Thani, Hat Yai and Bangkok Noi–three of them equipped for synchronous condenser operation. In total, they add up to 29.6 MW of diesel and 165 MW of gas generating capacity.

The oil-fired additions, needing imports at the expense of scarce hard currency, were invariably emergency measures and EGAT decided to expand the lignite programme late in 1973, as soon as the first bite of the oil crisis was felt. Instant bids were invited for the expansion of both the powerplant and the mine at Mae Moh, and the installation of the first 75 MW generating unit started late in 1974 and was completed early in 1977. Since then, a second unit has been commissioned and a third is about to go on stream, raising the capacity of the Mae Moh plant to 238 MW.

There is also further expansion planned by the time the 500 kV transmission link becomes operational.

Expansion programme

EGAT's first expansion programme for the country's transmission lines occurred from 1971 to 1974. Three lines—a 40 km-long 69 kV, eight 115 kV with a combined length of 581.5 km and a 96 km-long 230 kV—were added, along with 12 substations with a total capacity of 377 500 kVA, additional transformer capacity of 377 500 kVA to 19 existing substations, as well as shunt capacitors and other equipment to improve the over-all operation.

Currently the network incorporates 2242.81 km of 230 kV, 3507.38 km of 115 kV and 1023.38 km of 69 kV lines and 77 substations with 2 665 440 kVA of total transmission capacity, and the 500 kV transmission link (and grid by the 1990s) will represent a totally new development in this area.

Thailand's nuclear power generation plans are concentrated for the time being on a first-stage 600 MW station on the east coast of the Gulf of Thailand at Tambon Ban Aow Phai in Chon Buri province, 120 km from Bangkok, but this project, just as lignite-fired generation, is dwarfed in terms of reliance on domestic resources in comparison with the country's rapidly expanding hydro programme.

Current projects

A number of hydroelectric projects are either already underway or at the design or feasibility stage, and they feature highest in the race against time to minimize the effects of oil price rises and to keep abreast with the Government's fast economic development programme, which centres on the Mekong Plan and has in the past decade resulted in an increase in energy demand equivalent to approximately 20 per cent per year. The Mekong Plan, aimed at off-setting climatic and regional variations and at taking agriculture and industry to the sparsely populated, arid highlands is also directly underlined by the irrigation/hydro programme.

EGAT inherited three plants and multipurpose dams. Of these the 154 m high Bhumibol dam, built in 1964 and 486 m long at the crest—with reservoir capable of holding 13,462 X $10^6 m^3$ of water, supplies the city of Bangkok with water and controls the salinity of the Chao Phraya and Tachin Rivers, as well as irrigating the whole of the Chao Phraya basin—is the oldest and had for a long time been the largest not only in Thailand, but also in south-east Asia. The power station, equipped with six generators, has a total installed capacity of 420 MW. The Ubol Ratana and Nam Pung dams and power stations, built in 1965/66 at Amphoe Nam Pong in Khon Kaen and at Amphoe Kud Bak in Sakon Nakhon provinces respectively, are considerably smaller. Ubol Ratana has a 2560 X $10^6 m^3$ reservoir and three 8.3 MW generators, totalling 25 MW capacity, and for Nam Pung the equivalent figures are 165 X $10^6 m^3$ and two 3 MW units. The average annual energy output of the three oldest stations is 1500, 65 and 15 million units, respectively.

EGAT added four further hydro stations by the end of 1974, raising the country's hydroelectric capacity to 909.3 MW by that time. The Sirindhorn project, with a 1550 X $10^6 m^3$ reservoir and two 12 MW generating units was completed in 1971, and a third unit was added in 1978, raising the total capacity to 36 MW. Construction of the Chulabhorn project began in 1970, and was completed, with a 188 X $10^6 m^3$ reservoir and 40 MW capacity, in 1972. One 20 MW unit has added since then to the power station, which in this case is a considerable distance away from the dam. The Sirikit and Kang Krachan projects on the Nan and Phetchaburi Rivers with an 11 X $10^6 m^3$ and a 3.81 X $10^6 m^3$ reservoir, and installed capacities of 375 and 19 MW, respectively, entered into service in May and August 1974. Since then a fourth 125 MW unit has been added at Sirikit.

Future schemes

In 1980, two further projects are scheduled to provide new hydro capacity. One is the Pattani project with a dam at Bang Rang and a power station with three 20 MW units, and the other the Ban Chao Nen two-phase project on the Quae Yai River, which will eventually have 720 MW capacity. The first of the three 120 MW units scheduled for the first phase came on stream last October, the second in January and the third in June.

The construction of the Khao Laem dam and power station started early this year, on the Quae Noi River. Snowy Mountains Engineering are the consultants and project-managers, and Sheridan and Ital-Thai are jointly the main construction contractors. The project is expected to cost $362 million, towards which the World Bank has advanced a loan of $80 million.

The site is in western Thailand, where ethnic minorities abound and the building of the 80 m-high 900 m-long dam appears to coincide with a planned rearrangement of ethnic patterns since as a result of the flooding of the whole of the Sangkha district the population—51 per cent Thai and the rest Karen and Mon—will have to be resettled. The power station will be equipped with three 100 MW generating units by 1984.

In the north-east of the country, 56 km north of the town of Khon Kaen, the Pong Neeb scheme is in the hands of a consortium comprising Siemens Bau-Union GmbH and Philip Holzmann AG, both of the Federal Republic of Germany. Siemens are responsible for project management, and the 2500 X

10^6 m^3 reservoir will feed three 8 MW generators, as well as irrigate an area of 300 km^2.

A tripartite Japanese consortium, comprising Nippon Kokan, Mitsui Engineering and C. Itoh, is to supply EGAT with a turn-key powerplant barge, which will be positioned on the estuary of the Khanom River in southern Thailand. With a generating capacity of 76 MW, it will be the world's largest barge-mounted power station.

The Kud hydro scheme in Chiang Mai, the Lang Suan project in Chumphon province and the Upper Quae Yai scheme in Kanchanaburi province are still only proposed developments, and 43 locations have been identified as promising tributary sites with potential for 140 MW generation and 320,000 ha of irrigation in a detailed study of the Lower Mekong basin, with Pa Mong prominent among them. This site has a potential generating capacity of 4800 MW.

MICRO-HYDRO INSTALLATIONS IN NEPAL

*D.L. Wright**

Hydropower in Nepal

Nepal is a mountainous country with many rivers that are fed both by runoff and snowmelt. There are many suitable locations for hydropower, and indigenous technologies exist to exploit it, mainly in grinding cereals. The Nepalese terrain both provides the scope for hydroelectric development and makes distribution very expensive. The Government is therefore interested in promoting small-scale, village-level hydroelectric installations, and various Government agencies and private aid institutions are involved in this effort.

The two main non-governmental agencies involved in designing and constructing small schemes are Balaju Yantra Shala (BYS), a company set up by the Nepal Industrial Development Corporation and the Swiss Association for Technical Assistance, and the United Mission to Nepal (UMN). BYS has installed 12 plants, two of which generate electricity, and has recently contracted with the Government to install six more. UMN has installed 14 plants, mostly in the Palpa District around Tansen. These are not electric generators; they are installed as a package with a rice huller, oil expeller and flour mill.

Both BYS and UMN has standardized on the Banki-Mitchell type crossflow turbine, which they have found to be suitable for most applications. A particular advantage of this design is that a standard diameter runner can be used (and hence standard jigs and tooling), while the width is varied to suit flow and power requirements. The details of the UMN and BYS standard designs are, however, different. The UMN design is more compact and, by using a sealed case, can incorporate a suction tube below the turbine, thus increasing efficiency.

Cost of hydroelectric systems

Table 1 shows cost breakdowns for six existing, or planned, small hydroelectric schemes. The figures are broadly comparable, through extracted from the reports of different agencies will varying formats for tabulating the data. Over-all costs per kilowatt installed are quite similar with the exception of Gajuri – where use was made of a long, existing canal (thus minimizing civil works), and which is located on a main road, which reduces transport costs.

The composition of the costs varies markedly, however. Generating equipment, as might be expected, shows substantial scale economies varying from over Rs. 10,000/kW to less than Rs. 4,000/kW as scale increases. The other items show no clear trends because they are all location-specific. ("Other" includes land acquisition, as well as design and supervision.) The stability of the total cost suggests that tradeoffs are made in selecting sites principally between the characteristics of the site in respect of ease of exploitation (which affects the civil works costs), and the distance of the site from the users (which affects transmission costs).

As a model for further calculations, table II shows the estimated capital costs of a 40 kW hydroelectric unit based on the average costs of the installations in table I (excluding Gajuri). Also shown are the capital

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Table I

Cost of hydroelectric schemes (Nepali rupees Rs. 10 = $ 1.00)

Site	Salleri	Ghandruk	Tangting	Okhaldhunga	Gajuri	Ramjator
kW	80	30	20	120	25	80
Civil works	437,000 (5,500)[a]	120,000 (4,000)	65,000 (3,250)	1,058,000 (8,800)	44,600 (1,784)	270,000 (3,375)
Generating eqpt.	347,000 (4,300)	185,000 (6,200)	202,000 (10,100)	501,400 (4,200)	156,000 (6,240)	293,000 (3,665)
Transmission	735,000 (9,200)	117,000 (3,900)	85,000 (4,250)	532,000 (4,400)	71,000 (2,840)	804,000 (10,500)
Other	90,000 (1,100)	43,000 (1,400)	34,000 (1,700)	221,600 (1,850)	–	201,500 (2,500)
Transport	113,000 (1,400)	11,600 (400)	8,800 (440)	125,000 (1,050)	–	59,000 (740)
Total:	1,722,000 (21,500)	476,600 (15,900)	394,800 (19,740)	2,439,000 (19,340)	271,600 (10,860)	1,627,500 (20,340)

Note: [a] Figures in parenthesis are Rs/kW

costs for a diesel installation of similar capacity based on a local study. The substantial reduction in transmission costs results from locating the generator at the centre of the distribution network.

Table II

Capital costs of model (40 kW installations)

	Hydroelectric	*Diesel*
	(Thousands of Rs.)	
Civil works	199	20
Generating equipment	228	200
Transmission	302	100
Transport	32	30
Other	69	90
	830	440

Within total cost, which averages about Rs.21,000/kW, the governors used at present form a small component (typically about 5 per cent). While an electronic controller under development might reduce this proportion by half, such changes do not in themselves significantly affect the viability of small-scale hydroelectric. The decision as to whether to use manual control initiated by warning signals, conventional (but expensive) hydraulic governors or an electronic device will depend much more on performance, reliability and serviceability than on price. For remote operations, the electronic governor has several potential advantages: it is easily transported; spare parts can be held on site for little extra cost; maintenance and adjustment is unnecessary after initial set up. The main alternative at present seems to be manual control.

The type of controller used has implications for the load factor, which is of such crucial importance. Manual and hydraulic systems effectively waste water power by restricting the flow (below what is available) to that needed to balance demand. The electronic controller keeps the generator at full load by diverting the full power between the main load and a ballast. If a useful ballast can be devised (such as pumping water to storage, heating water, or possibly storage cookers), then the total water power is exploited, giving a 100 per cent load factor. There would appear, therefore, to be considerable scope for use of the load controller provided it meets appropriate reliability and performance criteria.

Table III

Annual fixed operating costs of model 40 kW installations

	Hydroelectric	*Diesel*
	(Thousands of Rs.)	
Depreciation	22.9	24.4
Maintenance (incl. spares)	11.7	23.6
Loan repayment (10 yrs. @ 10 per cent)	135.0	71.6
	169.6	119.6

Table III derives estimated annual fixed costs for the two model installations. The largest item in both cases is the repayment of capital. This accounts for 80 per cent of the costs of the hydroelectric installations which makes likely errors in the older figures irrelevant. Depreciation for diesel is more than hydro, largely because the generating equipment is assumed to last for only 10 years against 33 years for the hydroelectric installation.

Variable fuel costs for the diesel are so significant that at anything better than a 10 per cent load factor hydro is more cost-effective. The cost of fuel at the roadhead is taken at Rs. 3.25/kg. Assuming four days transport at Rs. 06/kg/day then the variable cost comes out at Rs. 1.57/kWh. This takes no account of regular availability. Any interruption in supplies may have expensive consequences.

Total operating costs are equal for the systems at about 10 per cent capacity utilization; at 40 per cent capacity utilization, diesel is twice as expensive; at high utilization, hydro approaches grid electricity (at about Rs. 0.35) in cost; in either system, capacity utilization must be good if costs to consumers are to be acceptable; the very low (or zero) marginal cost of hydro means that offpeak or special category sales at very low prices can contribute to fixed costs.

Demand and load factor

The demand or benefit side of the equation is less clear. In cases where a load exists, or where a load can quickly be developed, there is little doubt that a small hydro scheme would be a good commercial investment.

Most cases are less simple. The installation would often be the first source of power available, and capacity utilization would be low while people switched from traditional sources of light and heat to electricity, and small industries developed on the basis of the newly available power. In such cases, rapid development of the market is crucial to commercial success, and it can be expected that early years of operation will be unprofitable. One small (360 kW) installation run by NEC had just this experience. After two years the maximum load was only 25 per cent of capacity. After four years the installation is overloaded.

HIMALAYAN WATER WHEELS: IMPROVING PERFORMANCE*

There are about 50,000 water-powered mills in the Himalayan foothills of India and Nepal. A modernized water wheel would mean increased efficiency and greater opportunities for a variety of mechanical operations such as the use of the trip hammer, bellows, jigsaws and lathes. Jean Gimpel, a technology historian, has developed small-scale models which incorporate technical innovations of indigenous technology. This may persuade the farmer to take a critical look at a device he has been using for years. The model, he says, has a visual and tactile language that is readily understood by the peasant and village craftsman.

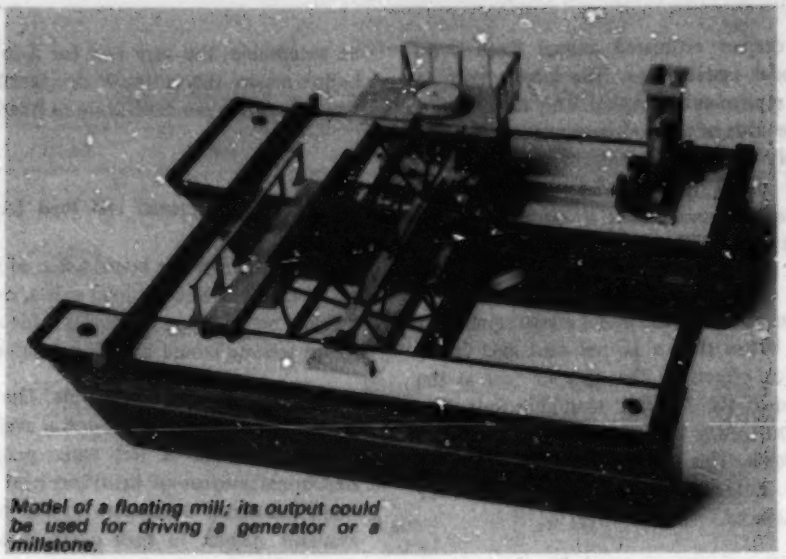
While updated technologies may not produce spectacular results, the gains are significant: the power of the new water wheel doubled initially, while improved capacity is still possible. Gimpel's models are indications of the directions in which rehabilitated technologies can move.

In November 1978 while Gimpel was in India to attend a UNIDO seminar on appropriate technology, he went to Solan in the hill state of Himachal Pradesh, in India. He took with him a model of a water wheel which incorporated various features of a late-nineteenth century Romanian water wheel. While the traditional Indian horizontal wheel has flat blades, the new version was designed with spoon-shaped blades which absorb greater energy from the water. This forms a simple turbine which rotates as the water strikes the angled wooden blades. The water chute was enclosed and the supply was directed and concentrated by a jet so that its velocity at the jet's outlet was greater than at the inlet.

Gimpel showed the model to a miller and a carpenter, who instantly recognized the advantages offered by the new version. When he returned to Solan in September 1979, although the modernization of the mill was still in progress, the carpenter had been making the new blades. The response in the village of Godavari in the Kathmandu Valley was the same. A miller, Govinda Mahajan, decided to use Gimpel's model. The building of the prototype mill was funded by the Research Centre for Applied Science and Technology (RECAST) at Tribhuvan University, Kathmandu. The Agricultural Development Bank of Nepal covered Mahajan's costs while the old mill was inoperative and the new one was being installed.

When Gimpel returned to Godavari in March 1980, several improvements had been made on his model. The miller had built a wooden box around the millstones to prevent the flour being blown away as had been the case previously. Mahajan estimated that about 3 per cent of the flour had been lost in

* This note was originally published in the "Research and development" section of *Water Power & Dam Construction* (ISSN 0306–400X, vol. 33, No. 1, January 1981), and is reprinted here with permission. Copyright 1981 by IPC Business Press Ltd.



Model of a floating mill; its output could be used for driving a generator or a millstone.

this way. Not only did the millstones move at 160 rev/min instead of 120, they gave better flour. The water wheel was originally of 1 hp; with the new model its capacity had doubled. An Indian engineer is working on improving output by enclosing the blades and shaft of the wheel. The Agricultural Development Bank of Nepal has ordered 50 models of the new wheel to show to farmers who, should they decide to modernize their wheels, would be given loans by the Bank.

Although Gimpel's design offers significant improvements, there are further modifications that could be made according to one group of experts. The Godavari's blades could be strengthened to cope with the greater impact of water. The chute could be a square section one with a detachable nozzle: this would facilitate removing any stones or bits that fell in. It would also be possible to produce a metal turbine.

While Gimpel has a model of a vertical water wheel, he feels that the horizontal wheel, already in use in the Himalayas, can be modified to produce alternative movement. He draws on the Spanish example: they have built vertical shafts above the millstones and the machines are driven off the shaft. In the standard milling machine this would mean putting the grain hopper to one side.

European models

The floating mill has harnessed the energy of European rivers since the sixth century A.D. About 1400 years ago, the Byzantine general Belisarius, was besieged by the Ostrogoths. The attackers destroyed the Roman Aqueduct of Trajan to stop the water mills from working. Belisarius' engineers moved the gearing mechanism and millstones of the mills to rebuild the machines on barges moored on the Tiber River, fitting them with paddles that were driven by the water flow.

Gimpel has devised two models of a floating mill; one shows its structure, the other represents it on the river. A vertical undershot water wheel consisting of a horizontal shaft and radial blades is fitted to the side of the barge, which must be moored to the bank or firmly anchored in the stream. A smaller barge supports the end of the shaft.

The hulls of the barges may be built along traditional lines and require no modification. Though the mill may not be used for devices such as trip hammers and stamps (these may cause too much vibration) the revolving shaft can be used for corn mills and jigsaws whose mechanism can be supported on the barge. A vertical rotating shaft can be obtained through a 90-degree gearing mechanism. Two sets of machines could be used if a wheel was fixed to either side. At flows of between 3 and 4 m/sec, a 5-m wheel will turn at about 4 rev/min.

The Chinese chain pump, a development of the Pater Noster pump, is also meant for rural irrigation and water supply. It consists of a tube, which could be made of wood, iron or bamboo. Through this runs a continuous chain fitted with a series of valves or washers. These are usually made of rubber. One Bangladesh village, says Gimpel, makes them from used car tyres. At the top of the tube the chain, with its washers, is hung over a wheel. The wheel is fitted with a handle which could be turned manually or by an animal. It can also be coupled to a water wheel or low-speed motor. The bottom of the tube rests in the water. The chain, turned by the wheel, comes up the tube, into which the water is forced by the washers. The water is then released at the top. The pump works very efficiently at a slow rate of rotation so the parts are not subject to a great deal of wear.

Gimpel not only sees the relevance of medieval European models in the third world today, he also advocates cross-country transfer of technology. The

Archimedean screw, perhaps one of the simplest devices for raising water, has been used in Egypt for the past 2000 years. Its application is mainly for irrigation: it can raise water to heights equivalent to one third of its length. Gimpel's model is in two complementary parts: one in perspex shows how it works, the other in wood displays its construction.

Making light

In Nepal the increasing costs of kerosene have threatened the cheap generation of light. Gimpel used the hydraulic power of the water wheel to experiment with the production of light. A simple bicycle dynamo hub was fixed to a revolving tyre coupled to the shaft of the mill. This produced light, an event that could have far-reaching economic and social consequences. An experiment carried out earlier in Dacca, Bangladesh, using a similar method produced only 4 W and the apparatus could not be repaired locally. But Gimpel's colleague, Ali Baghdadi, has designed an electric generator turned by a belt coming off the shaft of a water wheel. At 600 rev/min this should produce about 45 W, 13 V and about 3.5 A. The frame and the drum are made of wood and can be made locally; the magnets may have to be imported from countries like India. The generator is made up in a kit form and could be assembled and repaired locally. Such developments, of course, need review; evaluation would be part of the process of evolving an efficient system.

A PLAIN OF PLENTY GOING DRY?*

Vast land reclamation scheme leads to reduced rainfall, treatening plans for China's new 'Granary'

Chinese scientists have picked up worrying signs of possible environmental damage in the vast stretches of the north-eastern marshlands which have been reclaimed for agricultural use. Their concern led to an invitation to the United Nations University (UNU) to send a team for on-site inspection of reclamation areas in Heilongjiang Province. The following report is extracted from the UNU Newsletter *account of the team's mission.*

Even with the best of efforts at population control, realistic estimates still project that China will add at least another 200 million people to its already gigantic population by the end of this century. Thus China today is engaged in a crucially important search for new land to cultivate–in the short term to help feed those millions of new mouths each year, and in the longer term to ease the need for costly grain imports.

"Improving the existing status of land utilization is a key problem of Chinese agricultural development," Dr. Wu Chuan-ju, Deputy Director of the Institute of Geography in Beijing, told the land-use expert team. "In order to meet the needs of its expanding population, China has to open up more land for farming."

A September workshop in Beijing, with an accompanying visit to the north-eastern reclaimed areas, was one of the first fruits of a co-operation agreement signed in July between UNU and the Chinese Academy of Sciences. It brought together scientists from 10 countries–geographers, soil specialists, hydrologists and others–to discuss land-use problems in China, with particular focus on the signs of environmental damage in Heilongjiang Province, an area that now produces one sixth of all commercial wheat in China. Research by Chinese scientists indicates a sharp drop in rainfall and spreading arid conditions in that hitherto little-known corner of the country.

The importance of continued reclamation in China can be best demonstrated by a few statistics made available by Dr. Wu. At present, from 10 to 15 per cent of the 9.6 million km^2 of China are cultivated. While most of the rest of the country offers little hope of agricultural productivity, there is still an enormous area remaining–an estimated 430,000 km^2–which might be reclaimed and farmed. Reclamation thus has the potential of increasing China's cultivated land by one third.

One purpose of the UNU mission was to help the Chinese begin to develop some guidelines for future reclamation activities. But there were much broader implications; for clearly lessons could be drawn here that could be passed on to agricultural planners and policy-makers in other parts of the world.

Drop in rainfall

The site of the field visit was the Sanjiang Plain, the productive "heart" of Heilongjiang Province where nearly 2 million ha have been reclaimed since the mid-1950s. The drastic drop in rainfall in recent years dominated discussions. Here was the root cause

* This article was originally published in *United Nations University Newsletter* (vol. 5, No. 1, January 1981).

underlying all the other concerns about wind erosion, lessened soil fertility, drying swamps, and rivers that no longer flood.

The earth's land surface transfers water back to the atmosphere in two ways: through evaporation from the surface, and through plant transpiration. In turning 2 million ha of forests and humid swamps into farmland, the Sanjiang reconversion may have disrupted both these natural processes, and caused the drop in rainfall.

Facts obtained at the huge Qianjin State Farm, in the northern reaches of the plain, were typical of the disconcerting mix heard everywhere–evidence of both the land's productive potential to feed the Chinese people and the possible ecological peril that such an attempt posed. The farm is impressively organized: 9,000 inhabitants, about half of whom are workers in 22 brigades. There are 163 tractors, 100 combines, and a variety of other machinery. Administrative headquarters is a neat complex of well laid-out streets, with schools, medical dispensary, stores, and meeting halls. The farm has nearly 100,000 ha, 90 per cent of which was typical watery marshland before reclamation. Some 27,000 ha have been reclaimed to date. This land currently grows wheat, maize, sorghum and other food crops.

The visiting scientists were taken across newly ploughed black peat soil to the edge of a yet unreclaimed boggy area, a sea of windswept, yellow-brown grass in which footing is springy. "You can see that we still have a long way to go", a farm administrator told the group. "The water and land here is not yet fully utilized."

Other facts, however, left nagging doubts about the wisdom of pushing on into the virgin lands. Already the water table is down, by more than 2.5 metres in some places. Nature has shown a frightening ability to react to changes imposed by man. Sedges and other swamp flora had given way, in just one year, to a landscape of meadow thistles; a seemingly benign change until one considers the relative capacity of the two different land covers to return water to the atmosphere. Other reactions by nature had been more violent. After a sandstorm in May 1979, with winds approaching 90 km/h, the ditches along the farm roads were filled with precious black topsoil stripped from nearby fields. Elsewhere on the plain the same storm had swept away and buried thousands of hectares of wheat seedlings.

Which direction to go? Professor He Yong-qi, Director of the Heilongjiang Institute of Natural Resources in Harbin, suggested steering a route between a halt in further reclamation and clearing the land at will. "I believe the correct attitude should be reasonable exploitation with scientific management. Our task is to make the environment better with the help of science and technology, and with human activity. If we don't, nature is bound to punish us. The correct policy on the Sanjiang Plain should be 'control as a whole, advance in part'."

UNU will be helping the Chinese, in the future, to advance by establishing co-operative monitoring and agro-ecosystems research stations in the area. These will develop more precise information about environment changes in the Sanjiang Plain as reclamation goes on. There will also be broad dissemination to the world's scientific community of the knowledge gained in China, through UNU publication of the workshop proceedings and discussions in Beijing.

"We need a better understanding of the whole set of interlocking resource systems in the Sanjiang Plain", said Dr. Kenneth Ruddle, project co-ordinator for the University's study of water/land interactive systems. "Not only understanding the ecological counterbalances at work here–marshes *versus* farmland, and so on–but also knowing a good deal more about the human processes involved. What we learn here can contribute to our understanding of similar resource systems in other parts of the world."

Advantages in keeping water where it is ...

A machine that lays seamless plastic liner for a reservoir, canal or highway directly into soil at a depth of up to half a metre has been developed by researchers at the Technion-Israel Institute of Technology, Jerusalem. The four-metre-wide plastic sheets are laid in special configurations, eliminating the need to glue or weld the seams. The method, says Professor Dan Zaslavsky, head of the university project, is one half to one third cheaper than conventional methods. When used in agricultural fields, the liner has not been punctured by plants and in reservoirs, seepage has been reduced from 50 to 5 millimetres per day.

SOURCE: *Water Newsletter*, WIC, 19 November 1981

... or letting it go

Porous pavements permit water to enter and drain through them. And because they do, they offer a number of economic, environmental, and safety advantages, according to a report by three United States Environmental Protection Agency researchers. The advantages include lower costs, beneficial water quality impacts, reduced runoff rates and volume, flood and soil erosion control, and improved road safety. The report says that the goals of innovative storm water management of maintaining natural runoff levels by providing for infiltration, controlling runoff velocity, extending lag time, and reducing runoff volume can be achieved by the use of porous pavement.

SOURCE: *Water Resources Bulletin*, AWRA, August 1981

INFORMATION CHANNELS

Selected news and information on water resources developments in the Asian and Pacific region

Briefs

AUSTRALIA:

Forest catchments and water supplies

A Melbourne and Metropolitan Board of Works team is undertaking a hydrological research project in water supply catchments in the forested Healesville district, about 80 km from Melbourne. The project, which had its genesis in the mid-1950s when a series of small catchments was reserved for hydrology research, is investigating relationships between age and density of mountain ash forest and stream flow yield, and effects of timber harvesting on water quality.

Three creek catchments of 52.8 ha, 64.8 ha and 62.3 ha on the southern slopes of Mt. Riddell are being used in the study. In 1970 a series of access roads for timber harvesting was established in each catchment.

The first area, known as Piccaninny, was clear-felled in 1971, except for a 20-m buffer zone along the creek, and timber was recovered for milling or pulpwood. The catchment was burned in a controlled operation to remove accumulated debris and promote a suitable seedbed for regeneration of new forest growth. It was then resown with *Eucalyptus regnans* (mountain ash) seed at the rate of 4.5 kg/ha. Individual stem heights of up to 20 m have since been recorded in the catchment.

The second catchment area, Blue Jacket, was selectively cut to remove about half the established forest. Some areas were clearfelled, some thinned and others left untouched. There was no burning off or reseeding, regrowth being allowed to occur naturally.

The third catchment, Slip Creek, was retained in its natural state to act as a control catchment against which the behaviour of the other two could be measured.

According to the supervising engineer, it is too early yet to determine the long-term implications on water yield and quality: "This is a research project which will go on for another 50 years perhaps longer." However, after the clearfelling of the Piccaninny catchment, water yield increased substantially from a normal 250 mm to more than 550 mm, but is decreasing rapidly as the forest grows again. Soil moisture content in the top three metres also increased markedly after clearfelling, but has returned to pre-treatment levels. There was a smaller increase in stream-flow in the Blue Jacket catchment, which has been maintained subsequently.

A second experimental project was begun in 1969 in the North Maroondah catchment. It is designed to examine the long-term effects on water yield of manipulating stand density, either at the time of regeneration or at a later stage of forest development. This area contains extensive stands of dense mountain ash regrowth from the 1939 bushfires and areas of old-growth mountain ash forest. Each of 12 catchments, averaging 9 ha, has been equipped with a recording weir. A total of 33 boreholes, with an average depth of 5.2 m, have been established to measure soil moisture.

The Melbourne and Metropolitan Board of Works administers a total catchmnent area of 121,000 ha, of which 119,000 ha is forested. About 64,000 ha of this is covered by mountain ash type forest. The research programme has shown that catchments under mountain ash forest generate 70 to 80 per cent of Melbourne's water supply. The catchments have traditionally been managed as a single-use policy (i.e. water supply) with limited and organized public access. For some years there were repeated proposals from the sawmilling industry for access for timber harvesting.

Source: *Engineers Australia*, vol. 52 No. 12 (13-26 June 1980), pp. 22-23

BANGLADESH:

The Rower Pump

A new type of pump, the Rower Pump, has been developed in Bangladesh by the Mennonite Central Committee with help from CARITAS. The term "rower" is used because the pump is operated with a rowing motion. About 250 of these pumps were installed for use in Bangladesh in the 1979/80 winter season.

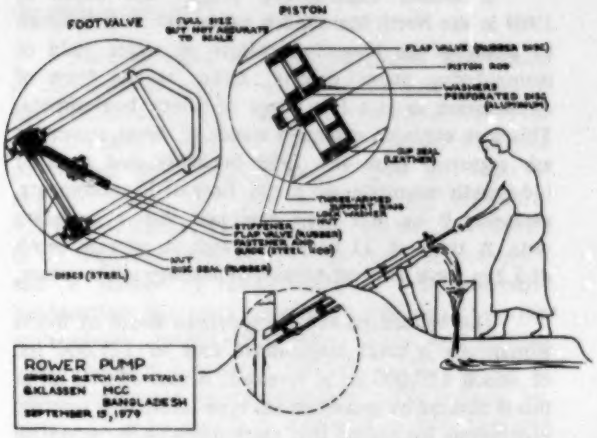
The pump is a reciprocating piston type with a two-inch polyvinyl chloride (PVC) pipe as the pump cylinder. The cylinder is inclined at 30° from the horizontal, thus the operator can push and pull directly on a "T" handle at the end of the piston rod. Besides being simple to maintain, the advantages of this pump are its low cost and ease of operation. Indeed a child could work it.

The rower pump has lifted water to nine metres, which may be within a foot or two of the maximum theoretical lift. This is made possible by the addition of a suction surge chamber on top of the tubewell and also because of the excellent seal provided by the

piston, which moves faster than that of conventional cast iron pumps.

Information on the pump may be obtained from Mr. George Klassen, MCC Rower Pump Consultant, 704 Poplar Bay, Portage la Prairie, R1N 3K8 Manitoba, Canada.

Source: Irrinews, No. 19, April 1980



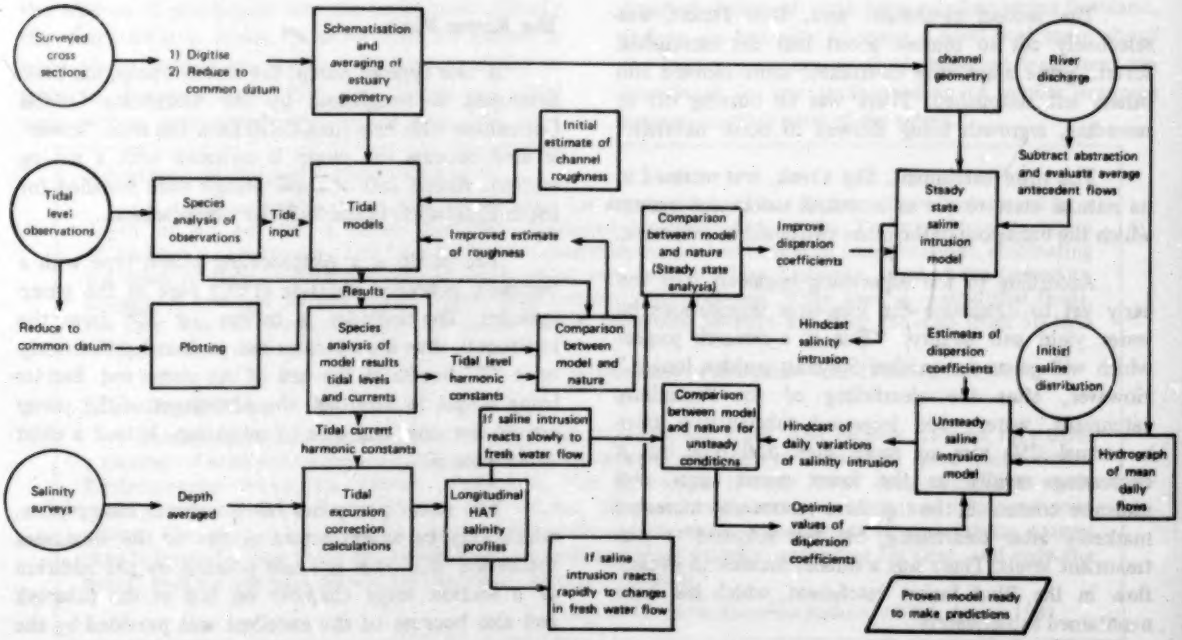
BRUNEI:

Saline intrusion studied

As increasing amounts of fresh water are abstracted from tropical rivers for industrial and agricultural purposes, sea water intrudes farther inland and contaminates fresh-water supplies abstracted from the tidal reaches of the rivers. A mathematical model developed by the Hydraulics Research Station (HRS) of the United Kingdom provides a quick and reliable method of predicting long-term salinity variations in estuaries having wide-ranging fresh-water flows so that optimum use can be made of both land water resources. This model was adapted by HRS in a commissioned study to simulate and predict intrusion studies in the Belait and Tutong estuaries of Brunei (see accompanying illustration).

A one-dimensional model was constructed and used to predict the extent of area-averaged saline intrusion at times of high astronomical tides using observed hydrographs of both wet and dry seasons. The model was then adapted and used to predict the intertidal motions and hence to determine the effects of increased rates of fresh-water abstraction from the tide-affected reaches of both rivers. These results were then used in calculations of the size of regulating reservoirs.

The mathematical model used in this investigation employed the High Water Slack techniques developed for such studies by the Overseas Development Unit of HRS Average values of salinity are obtained at cross-sections of the estuary, and the effects of tidal mixing are accounted for by the introduction of a longitudinal dispersion coefficient. The only field data required comprise longitudinal salinity profiles, taken about once a forthnight for about six months, together with data on geometry and daily river discharges. The geometry and tidal data, however, are limited to about one cross-section every 5 km and a few simultaneous tide curves. A standard 1-D flow model is used to hindcast and predict tidal excursions in the estuary. A special advantage of the model is that it is economical of computer time; this


Surveyed cross sections
1) Digitise
2) Reduce to common datum
Schematisation and averaging of estuary geometry
channel geometry
River discharge
Initial estimate of channel roughness
Subtract abstraction and evaluate average antecedent flows
Tidal level observations
Species analysis of observations
Tide input
Tidal models
Improved estimate of roughness
Comparison between model and nature (Steady state analysis)
Improve dispersion coefficients
Steady state saline intrusion model
Results
Reduce to common datum
Plotting
Species analysis of model results tidal levels and currents
Tidal level harmonic constants
Comparison between model and nature
Hindcast salinity intrusion
Estimates of dispersion coefficients
Initial saline distribution
Tidal current harmonic constants
If saline intrusion reacts slowly to fresh water flow
Comparison between model and nature for unsteady conditions
Hindcast of daily variations of salinity intrusion
Unsteady saline intrusion model
Hydrograph of mean daily flows
Salinity surveys
Depth averaged
Tidal excursion correction calculations
Longitudinal HAT salinity profiles
Optimise values of dispersion coefficients
If saline intrusion reacts rapidly to changes in fresh water flow
Proven model ready to make predictions

is because in operation it is able to sidestep the rapid fluctuations in salinity that occur during a tidal cycle, without a significant loss in accuracy.

In the present adaptation of the model, the time-dependent solution was achieved using finite difference methods rather than analytical techniques, and the model was modified to predict maximum limits of saline intrusion depending on the particular tidal conditions.

Future research. The prediction of saline intrusion is recognized as being a difficult problem, and is the subject of on-going research. Even the most apparently sophisticated mathematical model techniques employ relatively crude empirical relationships to prescribe mixing coefficients. The subject is at an early stage of development and considerable engineering judgement is required when applying the results of a prediction calculation.

Source: HY Summary No. 63, *Research and Commissioned Projects 1979*, Hydraulics Research Station, U.K.

BURMA.

Mini hydro boost

A technical assistance grant for the formulation of a mini hydropower project in Burma has been approved by ADB. The scheme will be designed to provide continuous power supplies, at a relatively low cost, to selected towns and neighbouring rural areas which are isolated from the country's main power grid. Ten mini hydro schemes located in various parts of the country, ranging in capacity from 300 kW to 4,000 kW and totalling 17,100 kW, are planned.

The power currently supplied to these areas by old and inadequate diesel generators is generally unsatisfactory in both quantity and quality, and is restricted to a few hours each night for lighting purposes.

Areas to be served by the project are agricultural, with industrial activity being limited to rice mills, oil mills, sugar mills, and sawmills. An economical and reliable hydropower supply would help to stimulate industrial growth in these areas and promote employment opportunities.

The technical assistance will help the country's Electric Power Corporation to formulate the project and expedite field investigations through the provision of required equipment. A team of experts will also be provided under the ADB grant for a total of 14 man-months, including a hydro civil engineer, a design engineer, a hydrologist and an economist.

Source: *Water Power & Dam Construction*, vol. 33, No. 3, March 1981

FINLAND:

Feed from waste water

A continuous-fermentation process to clean waste-water effluent and make animal-feed protein will be used at a sulphite pulp mill in central Finland, operated by G.A. Serlachius. The process, developed by Tempella of Tampere, Finland, will make 1,900 pounds of protein per hour, while reducing biological oxygen demand by 40 per cent. Investment costs are about $US 12 million. Biological water treatment had been considered at the mill as an alternative to the fermentation, but the company found it would be more profitable to produce protein. The process, which has been updated, allows the mill to operate on streams containing a low content of fermentable substances. Mill operations will use a condensate containing 2.5 to 3 ounces per cubic foot of acetic acid and some reducing substrates and alcohol.

Source: *Water Newsletter*, vol. 23, No. 2, (29 January 1981). Water Information Center, North Shore Atrium, 6800 Jericho Tpke., Syosset, NY 11791, United States.

INDIA:

Ancient rainforest threatened by dam project

Last-minute intervention by the Indian Government stopped the bulldozers of the Kerala State Electricity Board from beginning work on a dam to be built in the Silent Valley, south India's last area of untouched tropical forest. Prime Minister Indira Ghandi's predecessor Janata Government authorized the project in 1979, but start-up was delayed while conservationists petitioned the High Court. When that appeal was refused, Ghandi requested that Kerala's new provincial leader postpone the work and explore other alternatives. The Kerala State Government has agreed to reconsider.

The World Conservation Strategy has identified the ancient valley's 9,000-ha forest as one of the world's precious gene pools. Flooding the area for dam construction will destroy a wild variety of rice discovered to be resistant to major pests and other plants useful to medicine and crop scientists. Project opponents claim the genetic reservoir is more valuable to the country's development than the proposed water reservoir.

The dam project was originally approved early in the 1970s by the State Planning Board, chaired by Indira Ghandi. The resultant nation-wide protests brought forth a task force to study the proposal. They reported that a single monsoon could be expected to wash away the valley topsoil once the forest was bulldozed. Forest loss would also result in the swift alteration of local climate, since tropical forests play a vital role in moderating heat and trapping moisture

which slowly feeds into the ground. Their final recommendation was to abandon the scheme.

Although successive Kerala Governments have resolved to implement the project, the dilemma remains whether the legitimate needs of provincial governments and their people should take precedence over global interests in protecting the world's dwindling gene pools.

The Secretary of the federal (or central) Ministry of Agriculture recently asked in a report on a survey of the project, "Have we the right to deny to future generations the fruits of millions of years of natural evolution, just for adding about 7 per cent additional power to Kerala's vast energy resources?" The dam would add 60 MW to Kerala's 1,000-MW capacity, provide water to irrigate 10,000 ha, and its construction would employ 3,000 people. According to the *Bulletin of the International Union for Conservation of Nature and Natural Resources*, Kerala now has a power surplus which is sold to neighbouring States.

Alternative development proposals suggested by the Ministry of Agriculture include institution of a national rainforest biosphere preserve in the Silent Valley, an international research centre for the study of tropical rainforest ecosystems, an irrigation project committee to develop the State's ground-water resources, transmission of electricity from the nearby Idukki Dam to fill the immediate energy needs of the region, and allocation of the dam project budget towards suitable agricultural and industrial development.

A 14-member committee was appointed shortly after Ghandi returned to office this year to suggest a comprehensive approach to environmental protection. They have recommended giving constitutional authority to the central Government to intervene in any area to protect the environment. A central land commission was also proposed to regulate the placement of irrigation dams and other projects that would threaten the tropical rainforests.

Source: *International Water Report*, autumn 1980

INDIA:

Silting up sooner than expected

Up to three times the rate of expected sedimentation is being experienced on many Indian reservoirs, with the associated threat of reduced storage, and lower heads for hydropower. This was one of the major facts to emerge from the Nineteenth Congress of the International Association for Hydraulic Research (IAHR) held in February 1981 in New Delhi, India.

Dr. Kennedy, IAHR President, told *Water Power & Dam Construction* that silting was currently of such concern that hydro schemes involving large dams should no longer be considered as "renewable resources". As a result, small hydro has become even more attractive, although more work needs to be done on sediment management to mitigate the major problem.

Over 400 delegates attended the Congress where the subjects covered ranged from new instruments for measuring flow and silt to the prospects for small hydropower in the Punjab. S.L. Goyal of Punjab Electricity Board told the delegates that the only sources of hydropower in the Punjab were in the form of low head, and therefore the only possibility of benefitting from hydropower was to exploit these.

Source: *Water Power & Dam Construction*, vol. 33 No. 3, March 1981

INDIA:

New mortar for irrigation channels

The Indian Institute of Technology, Kanpur, India, has developed a process for making ashmoh cement from rice husk ash. Three raw materials are required: rice husk ash, lime, and a commonly available additive.

Compared to mortars based on Portland cement, ashmoh sand mixtures are more plastic, less harsh and easier to apply. Ashmoh has a finer structure and consequently a superior resistance to water pentration. It is therefore an ideal cement for water-storage tanks, and for lining irrigation channels and canals.

The production of ashmoh cement requires low capital investment, can be rapidly set up and is highly labour intensive. It can be manufactured in small units using local raw material.

Ashmoh is a patented process. Enquiries should be directed to UNIDO, P.O. Box 707, A-1011 Vienna, Austria.

Source: *Irrinews*, No. 19, April 1980

INDONESIA:

Reservoir sedimentation studied

Reservoirs constructed in areas of high erosion potential may have a short useful life, due to infilling by sediment. This can severely limit their economic worth, and it must therefore be foreseen if possible at the time when the feasibility study is carried out. Prediction, however, must rely upon the availability of suitable criteria.

As part of an investigation into this topic, two reservoirs in east Java have been surveyed to determine the degree of siltation since impoundment, and the distribution of sediment and its density within the reservoir basin. This information, together with records of continuous suspended sediment discharge, rainfall and riverflow, is being used to develop a method of predicting sedimentation in reservoirs.

The study is being undertaken by the Overseas Development Unit of Hydraulics Research Station (HRS) and has three main aims:

(a) To predict the total volume of sediment likely to be deposited within a reservoir.

(b) To predict the distribution of the sediment within the reservoir.

(c) To identify the sources of the sediment.

The work is being done by investigating the sediment deposited since impoundment in the Selorejo and Karangkates reservoirs, in east Java. In addition to measuring the deposits within the reservoirs, by echo-sounder, a network of rainfall, river flow and sediment measuring points has been set up in each reservoir catchment. Frequent measurement of these variables will make it possible to identify areas of sediment production and how that sediment is ultimately distributed in the reservoir.

Source: HY-Summary No. 59, *Research and Commissioned Projects 1979*, Hydraulics Research Station, United Kingdom

LAO PEOPLE'S DEMOCRATIC REPUBLIC:

Hydropower and irrigation from the Xeset scheme

The Xeset hydroelectric project in the Lao People's Democratic Republic is receiving preparatory technical assistance from ADB. A team of consultants will investigate the feasibility of constructing a hydropower station at a site on the Xeset River, about 30 km south of Saravane in the southern region of the country. They will then design a scheme which will include a powerhouse, associated transmission lines and distribution system.

Load centres covered by the project area will be the towns of Saravane and Ban Thateng. At present there are only two diesel generators of 50 and 100 kW at Saravane.

The Xeset scheme will also have benefits for irrigation and industry; Government plans for the development of the project area include irrigation pumping, rice and coffee processing, flour milling, saw milling, water supply, ice making and small factories for food processing.

Electricité du Lao will be the executing agency, and the technical assistance study will begin in April 1981. ADB and the Government of the Lao People's Democratic Republic will cover the foreign exchange and local currency components of the assistance, respectively.

Source: *Water Power & Dam Construction*, vol. 33, No. 1, January 1981

USA:

Satellite applications becoming less remote

While some progress has been made in remote-sensing applications to hydrology, recommendations made in 1974 to the National Academy of Sciences "remain valid but mostly unmet", concludes the National Research Council's Space Applications Board. Applications cited by a panel report include satellites such as Landsat, Seasat, the Heat-Capacity Mapper, and the Landsat-D. But, the panel notes, application has been too slow.

The panel optimistically views the use of remotely sensed data for resource prediction. However, "to be useful for prediction, remotely sensed data must be compatible with mathemathical modeling of hydrologic systems", the report says. Most water management models have to be improved if the information they produce is to be dependable and accurate. As a first step in the upgrading process it is recommended that the National Aeronautics and Space Administration (NASA) initiate "in-depth quantitative sensitivity studies designed to show what data and what information are likely to provide the greatest return." Remote-sensing data should then lead to models based on new concepts, and these models in turn could aid resource prediction.

Research priorities recommended for the coming decade include assessments of soil moisture, indirect indicators of the extent and depth of ground water, potential floods, rainfall, effects and sources of acid rain, suspended solids and salinity, lake eutrophication, and tidal regimes in estuaries. Emphasis could also be placed on operational applications and demonstrations of remote sensing for forecasts of runoff from mountain snowpacks, for surveys of aquatic vegetation, for surveillance of ice conditions, and for maps of land use.

Accelerating the research pace and improving the capability of remote sensing, the panel concludes, "can be expected to bring significant and relatively near-term benefits".

Source: *Water Newsletter*, 16 January 1981

USA:

1982 National Resources Inventory under way

The 1982 National Resources Inventory (NRI) being conducted by the United States Soil Conservation Service is the most comprehensive natural resource inventory ever undertaken by the agency. Data will be collected at 350,000 sampling sites throughout the country with statistical reliability down to the level of the major land resource area.

Data collected during the earlier 1977 NRI included land capability class and subclass, land use, rates of water and wind erosion, acreages of prime farmland, potential cropland, types 3 to 20 wetlands, and irrigation land.

Among the new data to be collected for the 1982 NRI are windbreaks, critically eroding areas, irrigation, cropping history, land cover, additional information on wetlands, riparian vegetation, wildlife habitat, additional information on soils, and supplemental vegetation data on pastureland, rangeland, and forest land.

Inventory techniques for the 1982 effort will consist primarily of field observations that will be recorded on an aerial photograph base map. From this base, a monitoring methodology will be developed that is consistent with current technology. This will include use of photo-interpretation techniques, satellite data collection systems, in-place sensors, and mechanized scanning.

Each of the sample points will be identified in a way that will allow access to a computerized soil information file. This access will allow detailed analyses of soil suitabilities and limitations and potentials for a wide variety of land uses.

An important use of these monitoring activities will be their integration with other data for prediction of phenomena. For example, integrating climatic data with soil moisture data for benchmark cropland soils would enable predictions of the probability and severity of drought, wind erosion, or flooding.

Source: *Soil and Water Conservation News*, vol. 1 No. 9, December 1980

ASIA/PACIFIC

Significant meteorological events in the ESCAP region in 1980

South-west Pacific

Temperature and sunshine: For most of 1980, it was exceptionally warm and sunny over much of the south-west Pacific. In Indonesia, temperature maxima exceeded 37°C during the dry season in Kalimantan (Borneo), Timor and Java. Adequate rainfall during the year was favourable for rice production which was estimated to have been about 12 per cent higher in 1980 than in 1979.

In Australia, a number of stations recorded their highest-ever January temperature, the most notable being 48.1°C at Carnamah, about 250 km north of Perth in Western Australia, and 46.8°C at Mitchell in Queensland. Brisbane had its hottest-ever summer, Sydney had its warmest-ever spring (after equalling its previous warmest-ever winter), and Canberra had its warmest April on record. It was the first time that the temperature at Sydney had exceeded 38°C in November and this occurred on no less than three days of the month. Dry weather in spring with temperatures between 2 and 5 deg C above normal was responsible for major bushfires in the states of New South Wales, Victoria and Western Australia from September to December. These resulted in losses of life and large areas of valuable forest, pastures and property. Despite the generally warm conditions, Tasmania had early frosts in February which ruined late-sown potato crops.

Sydney's mean daily sunshine of 9.0 hours for August and 9.9 hours for September were the highest ever recorded for these two months since sunshine duration measurements began in 1920.

Precipitation, floods and droughts: Large areas of southern Australia were affected by drought during much of the year. In New South Wales, many stations recorded their lowest-ever annual rainfall, and streamflows were close to the lowest on record. Farmers suffered livestock losses, marked shortfalls in wheat production and severe water shortages. The winter rainfall in Queensland was less than 20 per cent of normal in some places, forcing restrictions on irrigation. In the south-western part of Western Australia, it was the driest May-September period since 1914; in eastern New South Wales, November was the fifth consecutive month with below-average rainfall. New Zealand also suffered water deficiencies, especially in eastern parts of the South Island where Christchurch recorded only 17.4 mm of rain between 17 August and 5 November.

Heavy rains during January and February occurred in north-western parts of Australia. Widespread flooding caused extensive property damage and closure of roads. A few stations in the north of Western Australia set new daily rainfall records, in some cases in excess of 200 mm. An exceptional rainfall total of 805 mm associated with the incipient tropical cyclone Paul was registered at Binbee, near Bowen (Queensland) on 7 January. This caused one of the worst floods of the century in the Don river basin. Total damage was estimated at over $A 4 million ($US 3.5 million). In New Zealand, flooding from heavy rains was also reported on two occasions in January over parts of

Southland, and again in early June in Otago. Incidentally, a sea-level pressure reading of 961 hPa, measured in a depression on 16 January, was the second lowest ever recorded in the country. In July and August heavy snowfalls in the Southern Alps resulted in avalanching that blocked mountain roads until October.

In Indonesia, torrential January rains produced flooding and landslides in southern Sumatra and eastern Java which resulted in 23 deaths. Thousands of people had to leave their homes and huge tracts of farmland were inundated. But even more disastrous were the heavy monsoon rains in western Sumatra and central and western Java in the year when more than 100 people were drowned or buried under landslides. At Padang, in western Sumatra, a record November rainfall of 889 mm submerged more than 60 per cent of the city, and at Purbolinggo, in central Java, a new record of 959 mm was registered compared with the normal amount of 421 mm. During the dry season there was enough rainfall to meet irrigation and domestic requirements.

Storms: The north-western coast of Australia near Port Hedland was struck by three major cyclones between 10 January and 17 February. Cyclone Amy moved southwards into the country on 9 January bringing high waves, heavy rains and strong winds. Cyclone Dean took a similar route, striking the coast on 1 February. This one was unusual in that strong winds persisted inland long enough to buffet Newman, more than 300 km from the coast. A third cyclone, Enid, crossed the shore near Wallal on 17 February with wind gusts estimated at 63 $m\,s^{-1}$. Galeforce winds over southern Tasmania in mid-March resulted in apple crop losses estimated at $A 1 million ($US 900,000) as well as damage to property and power failures. Thunderstorms and tornadic squalls brought havoc around Brisbane on 16 December, damaging more than 5000 homes and overturning a number of aircraft at Archerfield. The ravages were expected to cost at least $A 10 million ($US 9 million) to repair.

Asia

Temperature and sunshine: Temperature deviations of 5 deg C below normal prevailed over Asian USSR from western Siberia to Irkutsk and southwards to Kazakhstan during January, February and March. Such conditions are expected once every 20 years. On the other hand it was exceptionally warm in winter farther east in the Yakutski ASSR and the Chukotski National District; the mean January temperature at Oymyakon (about 600 km NW of Magadan) was 11 deg C above normal. The situation was reversed in April when there were negative departures of 6 deg C over the extreme eastern regions of the USSR (this occurs with a frequency of once in 40 years) while Kazakhstan experienced temperatures averaging 4 deg C above normal. Across the South Asian sub-continent a moderate cold wave occurred during the first week of February. Night-time readings in north-western India averaged between 6 and 7 deg C below normal. In Hong Kong, the period 30 January-10 February was the coldest 12-day spell since 1900.

An unusually cold March and April (temperatures between 2 and 5 deg C below normal) over much of the north of the People's Republic of China delayed crop growth. However, elsewhere across Asia the spring was generally warm. At the international airport of Kuwait it was the warmest April since records began in 1958. In India, the eastern coastal state of Andhra Pradesh had a severe heatwave during the second half of May causing the death of 40 people.

During the summer season, record low temperatures were reported across central China and Japan, whereas record high temperatures occurred in Kuwait and Hong Kong. In July and August, temperatures averaged between 1 and 3 deg C below normal across China and the mean August temperature of 24.8°C at Shanghai was the lowest for that month since 1873. During most of the summer, Japan was influenced by a stationary front which brought cool, wet and cloudy weather. At many stations, record low temperatures were observed. For example, Miyako on the NE coast of Honshu had an August mean of 18°C, the lowest since observations began in 1884. Chilly wet weather adversely affected agriculture with losses estimated at 692 thousand million yen ($US 3200 million). By contrast, Okinawa enjoyed record warmth and sunshine. July was the hottest month on record at Kuwait airport with daily maxima exceeding 45°C on 24 days. In Hong Kong, several warm spells occurred in June and again in August; the temperature reached 33°C for eight days in succession (17-24 June) which was a new record for June since the start of observations in 1884.

The weather warmed across China in October and November with positive deviations ranging between 2 and 4 deg C. In November, exceptionally high night-time temperatures were reported from the western part of Madhya Pradesh in India. Asiatic USSR also experienced unusual autumn warmth, especially southern Kazakhstan and Uzbekistan, where November temperatures were between 6 and 7 deg C above normal. Such a departure from normal occurs only once every 30 to 50 years. At the same time, record negative deviations of 9 and 10 deg C occurred in Chukotski.

Precipitation, floods and droughts: During the winter, northern areas of India received only scanty precipitation, thus threatening normal irrigation supplies and crops planted in autumn. Winter dryness also affected the sugar and rice crop in northern Thailand. In Kuwait, February was very wet with 54 mm of rainfall, but April and May were exceedingly dry with only 3 per cent of normal precipitation.

In China, excessive rain was reported throughout the summer season, especially between the Chang Jiang (Yangtze) and Huai He rivers. July and August totals of between 450 and 700 mm were 50-150 per cent above normal. At Shanghai the July rainfall totalled 455 mm, the highest for that month since 1873. There were as many as 38 rainy days during July and August. The water level of most rivers, lakes and reservoirs was kept high and some floods in Sichuan were described as the worst in 30 years or more. But in the lower reaches the Huang He (Yellow River) and in much of north and north-eastern China the rainfall in July and August ranged from 20 to 80 per cent of normal, and at Beijing it was the driest summer since 1867.

During the host weather season, north-eastern India had normal or above-normal rainfall whilst the rest of the country had a precipitation deficit. Five out of seven depressions which formed during the south-west monsoon season developed overland which was rather unusual. Most of them affected eastern Uttar Pradesh which had a large precipitation excess for the season as did Punjab. Over the rest of the country rainfall at this time was about normal. Floods claimed about 1200 lives in Uttar Pradesh, and losses were estimated at about $US 325 million; 29,000 km^2 of crops suffered damage. Flooding was also reported in West Bengal, Haryana, Gujurat and Kerala. Unprecedented flash-floods in mid September of the River Vansadhara near the north-eastern extremity of the Eastern Ghats caused some loss of life and considerable damage to property. During a monsoonal cloudburst on 31 July, Lahore in Pakistan received 333 mm of rain in a 24-hour period which flooded low-lying areas of the city. The threat of rising floodwaters in northern India, Pakistan and Thailand necessitated the evacuation of millions of people. Along the western coast of Japan, the summer rains were the heaviest since 1908. At Ebino in the Prefecture of Miyazaki (eastern Kyushu), 630 mm of rain fell during the period 6-14 July, and another heavy accumulation was registered on 29-31 August. Casualties and extensive property losses were associated with both events.

No floods or droughts were reported in Burma, although in Thailand a number of intense September rainstorms over large areas of the north of the country and around Bangkok caused severe flooding from early September to mid November. Nearly a million people were evacuated and total costs were estimated at $US 7.7 million. In Bangkok, the flooding resulted from the combined effects of excessive runoff and periodic intrusions of high tides during October. The authorities declared the floods of 1980 to have been one of Thailand's most disastrous natural events ever. In the Republic of Korea, heavy monsoonal rains also wrought havoc in the province of Chungchong. On 21 July, several towns registered rainfall amounts in excess of 200 mm. More than 305 km^2 of cropland was flooded, roads were washed away and 173 people were reported dead or missing.

Storms and tropical cyclones: In Asian USSR, there were hurricane-force winds which blew heavy snowfalls into drifts on at least two occasions in March and November in eastern parts of Kamchatka and Sakhalin.

In northern India, several violent squalls with hail and heavy rain caused extensive damage to tea plantations, fruit orchards, vegetables and cereal crops between March and June. A severe dust storm and fire during the first week of May in eastern Uttar Pradesh claimed 100 lives and property losses of $US 1.2 million. On 24 June a sudden downpour triggered off a landslide in Uttarkashi in the Himalayan foothills. Many homes were damaged and 24 people lost their lives. Tropical storms were generally fewer than normal in the vicinity of India in 1980. Three cyclonic disturbances developed in the Bay of Bengal before and after the full monsoon season but none caused any serious damage.

The report from Thailand noted three significant tropical depressions on 21 May, 6 September and 17 September. Each storm had similar 24-hour maximum rainfall intensities of approximately 150 mm. Of the nine typhoons that affected China during the year (which is about the normal number), seven made landfall in Guangdong province, and no less than four of these were in the second half of July which is a very unusual occurrence. Two typhoons are mentioned in the report from Japan. On 11 September, typhoon Orchid, with a central pressure of 962 hPa, produced between 300 and 600 mm of rain in eastern parts of Kyushu and Shikoku and in the Kii Peninsula south of Osaka. There were 11 deaths, 77 injuries and 5500 houses flooded. Orchid continued across the Sea of Japan bringing rain and strong winds (30-35 m s^{-1}) to the eastern coast of the USSR. On the morning of 12 October a second typhoon, Wynne, passed west of Okinawa and travelled slowly to the vicinity of Tokyo. At its peak intensity, Wynne had a central sea-level pressure of 890 hPa and wind speeds of 77 m s^{-1}. Four persons were reported dead or missing, 28 injured and 2400 hourses inundated. The cost of Wynne's brush with Japan was ¥ 17 000 million ($US 79 million). Hong Kong was threatened by ten tropical cyclones during the year, but only typhoon Joe on 22 July came near enough to have serious consequences. Three people were killed and 59 injured.

Source: From an advance copy of the manuscript of an article to be published in *WMO Bulletin*, vol. 30, No. 4 (October 1980), provided by WMO.

Sources

NOTES ON WATER INFORMATION RESOURCES

first issues

Wamana

A new Indian quarterly newsletter, *Wamana*, is being issued by the Professional Interchange Unit (PIU) for the dissemination of information on water management. PIU was set up in August 1980 on a Ford Foundation grant, as part of the Project for Support of Research and Professional Interchange in Water Resources Planning and Management in India. The objective of the entire project is the strengthening of the growth of the water resources, planning and management sector in India by promoting research studies and professional interchange.

PIU, based at the Indian Institute of Management in Bangalore, aims to help in the "formation of a competent and cohesive group of water resources professionals in the country and to foster and encourage co-operation among them to tackle problems of national relevance". Apart from publishing *Wamana* and occasional bibliographies, PIU will organize workshops and symposia on important aspects of water management.

The first issue of *Wamana*, published in January 1981, contains details of 25 irrigation and irrigation-related projects and documents the deliberations of four recent conferences and seminars. Forty-five recent publications on water management are listed, as well as the 34 research centres in 19 states involved with the co-ordination of the Research on Water Management Project.

This newsletter should be of interest to all those who are concerned with the development of water management in the South Asian subcontinent. Contact address: A. Sundar, Indian Institute of Management, 33 Langford Road, Bangalore 560 027, Karnataka, India.

Water Management News

The publication of the first issue of the newsletter *Water Management News* is a landmark for the 11-year-old Water Management Synthesis (WMS) Project. The Project evolved from two programmes, one begun in Pakistan in 1970 and the other in Egypt in 1977.

In Pakistan, an interdisciplinary team of Colorado scientists working closely with their Pakistani counterparts and with the participation of farmers developed a systematic, three-phase procedure which involved identifying irrigation problems on small farms, searching for solutions, and implementing these solutions at farm level. Water loss was reduced by up to 50 per cent on small farms, and land crop production increased on selected farms by as much as 250 per cent. As a result, $US 200 million has been designated for the continuation of this project in Pakistan.

The Egyptian project has also proved successful. In some areas rice and cotton production has been increased by 35 per cent and 28 per cent, respectively, and the production of corn and flax has also improved. WMS Project activities are not confined to Pakistan and Egypt, but the experience gained there is being utilized for the benefit of farmers in other countries. An analysis of irrigation in Bangladesh, Nepal and Pakistan by an interdisciplinary team was completed in 1980. Similar analyses are scheduled for India, Thailand and other Asian countries.

For each country the WMS team prepares strategies for improved irrigation and defines the role of USAID in irrigation improvement.

WMS handbooks describe water management procedures which have proved to be successful at one location, and may be applied in other settings. The handbooks provide short descriptions, or captions with appropriate illustrations or photographs. This makes them suitable for a much wider audience than the standard manuals, for which a good understanding of English is required. Four of the handbooks cover: (a) land levelling, (b) farmer involvement, (c) pumps and pumping, and (d) small irrigation structures.

Other WMS publications include: (e) improving agricultural production through on-farm water management, (f) improving on-farm water management through irrigation associations, and (g) problem identification training manual for on-farm irrigation systems. WMS special reports include evaluations of irrigation systems at farm level in various countries or regions. A technical report is due to be published on design and evaluation of level basin irrigation, furrow irrigation and graded border irrigation.

The WMS Project is funded by USAID and managed by the Colorado State University and Utah State University. With the publication of this newsletter, the project leaders aim to share their experience with an interested audience. Contact address: Dan Lattimore, Editor, Department of Technical Journalism, Colorado State University, Fort Collins, CO 80523, United States.

Source: *Irrinews*, No. 23, 1981

networks

Engineers organized to respond to global emergencies

Twenty volunteer technicians comprise the core of the Register of Engineers for Disaster Relief (REDR),

established last year by a United Kingdom civil engineer. Applications from 100 other engineers are now being processed, with the hopes of keeping 200 to 300 engineers of all disciplines on line for immediate mobilization to any area hit by natural or man-made disasters.

Peter Guthrie was prompted to form REDR after his work with Oxfam for the boat people in Malaysia. Oxfam, a British-based agency, is skilled at gathering materials and food for disaster relief, but finding specialists to supply water, sanitation and shelter has always been a difficulty for agencies like Oxfam, the United Nations High Commission for Refugees and the International Red Cross.

Registration with REDR has been proposed as follows. Volunteers would submit a summary of their qualifications and be interviewed by engineers experienced in relief work. They could then be appointed without further interviews. Availability limits, depending on arrangements made with their employers, would be included in the files. Appointments generally would be for a maximum period of three months, with volunteer stipends handled by the relief agency utilizing the register. It is estimated that approximately $US 25,000 a year will be needed for REDR to function effectively.

REDR has already supplied engineers for work in Malaysia, Somalia and Uganda. Inquiries can be directed to P. Guthrie, REDR, c/o Scott, Wilson, Kirkpatrick & Partners, Scott House, Basing View, Basingtoke, Hampshire RG 2JG, United Kingdom.

Source: *International Water Report*, Winter 1981. Water Information Center, Inc., North Shore Atrium, 6800 Jericho Turnpike, Syosset, NY 11791, United States.

International network for hydraulic information reaches out

Handling the growing flow of information on completed and on-going research requires the use of automated information dissemination systems. Besides traditional sources of information such as congress proceedings, technical and reference journals, an increasing number of computerized data bases becomes available. An example is the COMPENDEX data base, which covers the field of engineering. In 1981 it comprised 600,000 references, and it grows by about 80,000 references per year. In the field of fluid mechanics (and hydraulics) efforts are made by several institutes to complement their existing sources of information (reference journals) with computerized data bases. Examples are the British Hydromechanics Research Association (BHRA), Delft Hydraulics Laboratory (DHL) and Electricité de France (EDF), but there is no concerted action in this field.

The council of IAHR has decided to establish a Working Party on Documentation with the following tasks:

(a) To promote the use of existing sources of information such as reference journals and data bases by providing information to members in the *Journal of Hydraulic Research* and on congresses.

(b) To study the possibility of a common data base in the field of fluid mechanics. This will require funding by international organizations.

(c) To study the possibility of an information system on on-going research by members and corporate members.

As another measure, the council has decided, in addition, to start a pilot project in which more of the "grey" literature (reports and other documents with limited distribution) produced by members and corporate members is processed and immediately introduced in existing documentation systems (BHRA, DHL, EDF), making the information available through selective dissemination of information (SDI) and automatic information retrieval.

In order to implement this pilot project, a survey organized by EDF among member institutes will enable the evaluation of existing library and documentation facilities. Together with the result of the survey, the members will be informed on the proposed pilot project.

Corresponding address: Electricité de France, Dép. Systèmes d'Information et de Documentation, att. M. Pupponi, 1 Avenue de Général de Gaulle, B.P. 408, 92141 Clamart CEDEX, France.

Source: Newsletter No. 5 (March 1981) in *Journal of Hydraulic Research*, vol. 19, No. 1 (1981).

information centres

Ground-water Information: NWWA provides the resources

*Jean Poland**

Researchers in every discipline are being forced to deal with the exponential growth of scientific literature. As the number of journals, reports, and symposia proceedings grows, the literature pertinent to any given field becomes more and more scattered. This is particularly true for hydrogeology, wherein the publication of material with direct bearing on ground

* Information Services Manager, National Water Well Association, 500 West Wilson Bridge Road, Worthington, Ohio 43085, USA. This article is reprinted from *Ground Water*, (ISSN 0017-467X; vol. 18, No. 6, November-December 1980). Copyright 1980 by the Water Well Journal Publishing Company.

water is not limited to hydrological or geological journals. Information of interest to ground-water researchers comes from such diverse disciplines as aeronautics, petroleum engineering, agriculture, public health, nuclear engineering and chemistry.

The conflict between environment and energy has served to increase ground-water related research. As the public and politicians have become aware of diminishing water supplies and the problems associated with waste disposal, more money has become available for hydrogeologic research. Greater Federal emphasis on ground-water exploration, classification, and conservation will inevitably result in a tremendous increase in what is already an overwhelming amount of literature. Researchers who now feel inundated by this flood of information will find the situation worsening.

Over the past five years the staff of the National Water Well Association (NWWA) Research Facility has become increasingly aware of the difficulties of gathering information. Based on these problems and thousands of inquiries from other ground-water professionals, NWWA established the Library/Information Center to provide a central source of hydrogeologic information.

Ground-water literature collection

The Library/Information Center houses one of the leading ground-water library collections in the United States of America. Holdings number approximately 9,000 volumes including 120 journal subscriptions. Several hundred microfiche are included in the collection. Major water-related newsletters are also kept on file.

Special emphasis has been placed on the collection of appropriate technology materials, particularly those dealing with water well technology. These books and journals are geared toward both developing countries and rural America. Water supply, ground-water flow and pollution, drilling technology, waste disposal, and ground-water source heat pump materials are the other major subject areas covered.

All items in the collection, with the exception of reference material, are available for loan to ground-water researchers. Loans can be arranged either by contacting the Library/Information Center directly or through inter-library arrangements.

Library/Information Center staff members answer hundreds of ready-reference questions each year. These are inquiries which can be answered easily by checking reference books. The most frequently asked questions involve locating addresses of publishers, associations, and water research agencies. Occasionally callers are referred to other organizations specializing in surface water or water treatment.

Loans and ready-reference inquiries are handled at no charge. Photocopying charges vary according to the number of pages and amount of clerical time involved.

The collection and lending of ground-water materials is an important function of the Library/Information Center but it is by no means the only one. In fact, the cross-disciplinary nature of ground-water research makes it close to impossible for any single library to collect all published materials in the field. Space and cost limitations are added factors in keeping even a major collection from becoming totally comprehensive.

"What has been published" and "How can we get it" are the two questions hydrogeologists most frequently ask. The Library/Information Center is prepared to help find the answers.

Literature searching

The first problem confronting researchers is to determine what work already has been performed in their areas of interest. Because the possible sources of publications have become very diverse, literature searching is one of the most important services a library can offer. The NWWA Library/Information Center staff perform both manual and computer literature searches.

Manual searching. Abstracting and indexing publications, bibliographies, published computer searches, and journal indexes all can be searched manually. *Selected Water Resources Abstracts*, published by the United States Department of the Interior, is the most frequently searched abstracting publication. The Library/Information Center has a large and varied collection of water resources bibliographies which provide references in a variety of areas including irrigation efficiency, subsurface waste disposal, saline ground water, and thermal energy storage.

For the past nine years NWWA has provided input to *Selected Water Resources Abstracts* as a center of competence in water well technology. During that time, Library/Information staff have become very proficient at abstracting, indexing, and searching the literature.

Computer searching. When a researcher requires extensive and comprehensive searching of a subject, computer retrieval can often produce more complete references. Manual searching is limited to broad subject areas; subject terms in computerized systems can be combined with logical operators to produce precise citations. A very specific subject such as "digital models of ground-water flow in a semiconfined aquifer" lends itself to computer retrieval where the proper combination of search terms will eliminate retrieval of extraneous references.

Computer searching is also indicated when a researcher requires the most recent items published. Most bibliographic data bases are updated months before printed bibliographies and abstracts appear.

Currently, the Library/Information Center searches two international computer retrieval systems: Lockheed's DIALOG and System Development Corporation's ORBIT. The two systems provide access to over 100 data bases. A list of those most frequently searched and their subject coverage demonstrates the interdisciplinary nature of ground-water research, as follows.

APILIT– petroleum refining and petrochemical literature; produced by American Petroleum Institute.

APIPAT– petroleum refining and petrochemical patents; produced by American Petroleum Institute.

COMPENDEX– engineering literature; produced by Engineering Index.

ENERGYLINE– energy-related literature; produced by Environment Information Center.

ENVIROLINE– environmental and resources literature; produced by Environment Information Center.

GEOARCHIVE– geoscience literature; produced by Geosystems (London).

GEOREF– geosciences literature; produced by American Geological Institute.

INSPEC– physics and engineering literature; produced by Institution of Electrical Engineers.

NTIS– United States Government-sponsored research and development technical reports, produced by National Technical Information Service.

POLLUTION– environmental pollution literature; produced by Data Courier.

TULSA– oil and natural gas-related literature and patents; produced by the University of Tulsa.

Two new data bases of particular interest to hydrogeologists will soon be available on the ORBIT system. The on-line version of *Selected Water Resources Abstracts*; and WATERLIT, produced by the South African Water Information Centre.

Both ORBIT and DIALOG include the capability of on-line ordering of some materials. Costs for use of the systems vary according to the amount of time spent connected to the computer and the data bases searched.

Data base development

Hydrogeologists have no single data base available to which they can turn for information. The Library/Information Center is in the process of developing such a data base in co-operation with the Unites States Environmental Protection Agency.

In 1978 the Library/Information Center designed a prototype retrieval system. All Center holdings are entered on the system and can be retrieved by coded keyword, author, title, or call number. This system met with a great deal of success with both Research Facility staff and NWWA members who contacted the Library/Information Center with information requests. While the prototype system is limited to in-house use by NWWA information specialists, the new data base will be interactive and available to anyone with a computer terminal.

Ground-water related references will be retrievable by any combination of author, title, aquifer region, continent, country, state, county, chemical constituent, biological factor and keyword. This range of access point provides for the extremely specific searches necessary to pinpoint items of relevance to ground-water research.

The system eventually will be able to answer not only "what has been published" but also to provide the user with a source for the material. In the initial stage all NWWA holdings will be entered on the system; the second stage will involve expanding the data base with items held by other libraries, establishing a network of sources for hydrogeologic literature.

As the information requirements of hydrogeologists continue to grow, the Library/Information Center will make every effort to keep up with the demand. Services are available to all members of the ground-water research community, to supplement resources at their own institutions or to serve as the primary source for researchers without information support.

Ground-water research centre

A national centre for ground-water research has been established through a consortium of the University of Oklahoma, Oklahoma State University, and Rice University. Research at the centre will focus on four ground-water problems identified by the United States Environmental Protection Agency: "the transport and fate of pollutants, characterization of the rate-determining factors in the subsurface environment, development of methods for ground-water quality assessment and protection, and information transfer." Funds for the centre were provided by the United States Congress under the Anticipatory Research Program.

Source: *Water Newsletter*, vol. 23 No. 3, 13 February 1981

directories and information guides

Research Programmes in Environmental Engineering and Science in India, by B.B. Sundaresan, S.K. Kesarwani and S.G. Bhat, provides information on 462 research projects in the field of environmental engineering and science carried out in India by about 900 scientists working in different organizations. Sponsored by the National Environmental Engineering Research Institute in Nagpur, the 327-page volume (order code PB80-198492) is available for $US 18 from the National Technical Information Service (NTIS), 5285 Port Royal Rd., Springfield, VA 22161, United States of America.

Directory of Institutions and Individuals Active in Environmentally Sound and Appropriate Technologies was developed by INFOTERRA and the Environmentally-Sound and Appropriate Technology Task Force, components of the United Nations Environment Programme (UNEP), and is the first volume of the UNEP Reference Series. Over 100 countries are represented in the directory, and entries are categorized as follows: research organizations with some amount of experience and expertise; organizations expressing an interest in appropriate technology (AT), nor necessarily research-oriented; organizations interested in AT though not as a main focus; organizations supplying only an address and occasional attribute; and, individuals involved in AT regardless of the extent of their involvement. The 152-page, hardcover book is available for $US 20 from Pergamon Press Ltd., Maxwell House, Fairview Park, Elmsford, NY 10523, United States of America.

Water Quality Surveys - a Guide for the Collection and Interpretation of Water Quality Data was prepared by a WHO Working Group on Quality of Water, and has been published in the continuing UNESCO/WHO *Studies and Reports in Hydrology* series which was initiated in 1965 with the launching of the International Hydrological Decade. The Working Group was assigned the specific task of compiling a guidebook or manual of immediate practical use for water quality surveys. A great number of authors contributed to it. As well as discussing the scope of the problem, including legal and administrative aspects, the guidebook deals with such topics as water quality parameters, sampling techniques, water analyses, laboratory facilities, recording and processing of data, monitoring networks, and ground-water quality.

Water Pollution: a Guide to Information Sources (Allen W. Knight and Mary Ann Simmons, ed.) is an annotated listing which includes a wide range of information sources useful in researching various aspects of water pollution. The four-part book is arranged in sections covering a guide to general reference sources, water pollution reference sources, miscellaneous and appendices. Also included are author, title and subject indexes. Copies of the 278-page guidebook are available for $US 30 from the Gale Research Company, Book Tower, Detroit, MI 48226, United States of America.

Pollution Research Index: a Guide to World Research in Environmental Pollution (second edition, ed. by A.I. Sors and D. Coleman), contains 2,000 entries detailing research on the physical, chemical and biological properties of pollutants; their movement and transformations in air, fresh-water, marine and terrestrial environments; their effects on man and nature; and measurement and control techniques. Citations from research institutes, government departments, universities, and industry in over 100 countries include original and English-language title, address and affiliation, director of research and scope of activity. Nearly one third of the entries are new to the second edition, and many others have been updated. A subject index is included. The volume is available for $US 182.25 from Francis Hodgson, Longman Group Ltd., Longman House, Burnt Mill, Harlow, Essex, CM20 2JE, United Kingdom.

United Nations Water Decade Directory, published by *World Water* in collaboration with the World Health Organization, contains around 300 pages of digests indicating spending plans and priorities in each country for the International Drinking Water Supply and Sanitation Decade (1981-1990). The Directory is to be used by United Nations representatives and national governments in monitoring progress towards the Decade targets.

Each entry will include demographic, economic and social statistics; details of responsible government departments; current status (coverage) of water and sanitation; actions and projects required; potential for external co-operation; and expert assessments of each country's capacity to handle accelerated sector investment.

The directory provides a valuable aid in defining the markets for all water- and sanitation-based products and services. For further information, contact World Water, Telford House, P.O. Box 101, 26/34 Old Street, London EC1P 1JH, United Kingdom.

maps

Hydrogeological India

The first hydrogeological map of India was compiled under the direction of the Central Ground

Water Board at its Eastern Region headquarters, Calcutta, on a scale of 1:5,000,000 and published in 1976. Its legend will serve for the first *Regional Hydrogeological Map of South and East Asia* being compiled.

The Hydrogeological Map of India represents a synthesis of all available information on geology, structure, geomorphology, climatology, hydrology relevant to hydrogeology of the country. This map attempts to project the regional hydrogeological environ, highlights its prevailing characteristics and quantifies the ground-water regimes, suitably modified through a legend based on the accepted UNESCO/IAH International Legend, 1970.

Source: *Hydrology Review*, vol. 3, No. 4 (October 1977), Indian National Committee for the International Hydrological Programme.

River basins of the United States of America

The first nation-wide map delineating boundaries of the major river basins in the United States has been developed by the United States Geological Survey and the United States Water Resources Council. The hydrologic unit map is designed to provide a standard geographical framework of detailed planning for water and related land resources. The map outlines both natural and man-made stream-drainage areas and designates areas by a hydrologic unit code that identifies the four hydrologic levels into which the country has been divided for purposes of water-resources planning and information management. Copies of the "Hydrologic Unit Map of the United States" may be obtained for $US 3.00 from the Branch of Distribution, United States Geological Survey, 1200 South Eads St., Arlington, VA 22202, United States of America.

Source: *Water Newsletter*, vol. 23, No. 4 (27 February 1981)

proceedings

The Influence of Man on the Hydrological Regime with Special Reference to Representative and Experimental Basins is the published proceedings of the recent symposium of the same name held at Helsinki, held 23 to 26 June 1980 as part of the International Hydrological Programme. Included in the proceedings are 70 papers from 28 countries dealing with the consequences of human influence on the quantity and quality of water. The proceedings are available for $US 75 from the Office of the Treasurer, International Association of Hydrological Sciences, 2000 Florida Ave., N.W., Washington, DC 20009, United States of America.

Hydrological Forecasting: Proceedings of the Oxford Symposium, April 1980 contains over 70 papers from 22 countries represented at the Symposium. The meeting was cosponsored by UNESCO, WMO and IAHS, and addressed recent developments in hydrological forecasting and its application in resource management. Papers include a flood-forecasting data acquisition system, soil freezing and thawing dynamics in a model of runoff from snowmelt and rainfall, control of salt-water intrusion in estuaries by means of a dual-purpose reservoir, forecasts of large river discharges taking into account the non-uniformity of precipitation over a basin, use of data from remote sensing sources for hydrological forecasting, and simple self-correcting models for forecasting flows on small basins in real time. The 571-page volume is available for $US 75 from the Office of the Treasurer, International Association of Hydrological Sciences, 2000 Florida Ave., N.W., Washington, DC 20009, United States of America.

Proceedings of the Ground-water Pollution Conference, 1979 have been published, on Australia's first national ground-water pollution conference which was held in Perth from 19 to 23 February 1979, sponsored by the Australian Water Resources Council. This publication is the first in the Council's new Conference Series.

A total of 30 papers were presented at the Conference. These cover a range of subjects and include case histories highlighting major ground-water pollution issues in Australia and New Zealand; theoretical modelling of ground-water pollution problems; issues emerging from the land treatment and ground-water treatment of wastewater; and information concerning the nature, origin and physical characteristics of pollutants and the transport mechanism involved.

Copies of this publication will be distributed shortly to addresses on the Council's mailing list. It may be purchased through Australian Government Publishing Service bookshops.

River Pollution Control (ed. by M.J. Stiff) describes the scientific, legal and political measures currently being taken to protect world rivers from pollution. Resulting from a conference sponsored by the Water Research Centre (United Kingdom) in April 1979, the volume offers contributions by regional, national and international authorities in this complex field of study. The book addresses problems of the European countries, particularly those with trans-frontier rivers; measures adopted to improve river

quality; and how international agencies such as the World Health Organization can co-ordinate action. Data requirements for local control and for central government are included, along with two novel methods of assessing water quality. The 423-page volume is available for $US 99.95 through Halsted Press, John Wiley & Sons, Inc., 605 Third Ave., New York, NY 10016, United States of America.

Wastewater Reuse for Ground-Water Recharge is the proceedings of a symposium held September 1979 in Pomona, California. The 345-page volume emphasizes quality, health, criteria, reliability, treatment monitoring and international aspects of reclaiming wastewater for ground-water recharge. Published by the California State Water Resources Control Board, the proceedings are available for $US 9.50 from Documents Section, California Department of General Services, Office of Procurement, P.O. Box 1015, North Highlands, CA 95660, United States of America.

Abstracts from the International Symposium on Artificial Ground-water Recharge, held 14 to 18 May 1979 in Dortmund, Federal Republic of Germany, are available for 15 DM from: Dr. Schmidt, Institut fur Wasserforschung, Geschaftsfuhrung, 4600 Dortmund 1, Federal Republic of Germany.

Hydrological Aspects of Droughts is the proceedings of a symposium held 3 to 7 December 1979 in New Delhi. Forty-nine papers deal with such topics as effects of droughts on morphology of land regime, water regime and water quality, trends and predictions of droughts, systems management, and case studies. A key paper given by A. Krishnan defines droughts and factors relevant to specification of agricultural and hydrologic droughts, computing the daily or weekly water balance rather than relying on the less meaningful criterion of rainfall. The proceedings can be obtained from Prof. Subash Chandra, Department of Civil Engineering, Indian Institute of Technology, New Delhi 110 019, India.

Scientific Aspects of the 1975-76 Drought in England and Wales discusses the impact of the 1975-1976 drought through its effects on farming, river behaviour, experimental catchments, the loads imposed on surface- and ground-water resources, the planned and utilized devices for dealing with shortages, and sewage disposal and other pollution problems. The volume is the result of a meeting held in 1977 on behalf of the British National Committee on Hydrological Science. The book summarizes the recorded data and analyses the experience gained from the worst drought in England and Wales in 200 years. Suggestions are included for future development of water resources in the United Kingdom. The publication is available for $US 16.50 from the Royal Society, 6 Carlton House Terrace, London, SW1Y 5AG, United Kingdom.

Australia's Offshore Resources: Implications of the 200-Mile Zone (ed. by G.W.P. George) is a collection of papers given at a symposium of the Australian Academy of Sciences in 1977. Australia's 20,000-km coastline is one of the world's longest, and the country is surrounded by the most extensive continental margins in the world. The published papers cover legal, political, economic, and management factors pertinent to their vital 200-mile exclusive economic zone. Close attention is given to estimating Australia's resource potential. Further information about the 143-page volume is available from the Australian Academy of Science, P.O. Box 783, Canberra City, ACT 2601, Australia.

published in the region

Dam Construction by the Chinese People has been published by the Chinese National Committee on Large Dams. The book describes the wide range of technical problems, designs and construction methods used while building over 300 reservoirs with a capacity greater than 100 million m^3, 2,100 medium reservoirs, and more than 79,000 small reservoirs in the 100,000-m^3 range completed since the People's Republic was founded 31 years ago. Chapters include earth dams built by sluicing-siltation methods, and by soil-dumping into ponded water; rolled-fill earth dams; overflow earth-rock dams; light-type concrete dams; barrages and dams constructed of precast units; and dams of simple construction. The volume is available for $US 30 from the National Committee on Large Dams, P.O. Box 366, Beijing, People's Republic of China.

Industrial Water: Use, Reuse and Disposal has been published by the Melbourne and Metropolitan Board of Works. The recent introduction of new policies for the discharge of trade wastes to the metropolitan sewerage system of Melbourne has focused attention on the possible measures which might be introduced by consumers to minimize trade-waste charges and to achieve the required standards of waste-water quality. At the same time, there is a growing awareness of the possibilities for recycling and reusing water, and for greater water-use efficiency within industrial processes, all of which can result in reduction in the volume of, and hence the charges for, fresh-water supplies

and trade-waste discharges. The possibility of recovering valuable materials from waste water is also receiving attention.

The contents of this report include:

(a) *Water-use in industry*—main uses of water, supply and disposal of water; water quality requirements; treatment processes;

(b) *Opportunities for water conservation*—possible measures (eliminating wasteful consumption, water reuse and recycle, use of non-potable supplies); industry case studies (food canners and packers, abattoirs, bottlers, pulp and paper industry, dyers, chemical process industry, electroplaters);

(c) *Trade waste control*—charging and acceptance policies; process engineering for trade wastes (general, preventive strategies, modifications to existing processes, installation of waste treatment facilities); examples (general, use of alternative feedstock, treatment of use of wastes to produce a usable or saleable product, integration of a treatment stage into the over-all manufacturing process, separate facilities for treatment of waste before discharge to sewer: metal finishing wastes/dyehouse effluent/dairy wastes/distillery wastes).

Comparison of the Common Australian 203-Millimetre Rain Gauge with the WMO Reference Pit Gauge, by M. Tauman, P.J.R. Shaw, and M. van Dijk, describes how the Australian Bureau of Meteorology conducted a comparison of the normal Australian 203-mm rain gauge with the WMO reference pit gauge. The latter is installed in a pit so that the rim of the funnel is flush with the ground and surrounded at ground level by an anti-splash grid. The pit gauge is assumed to be unaffected by wind. Data of 197 station-months were collected at six stations in Australia and Papua New Guinea, and results are contained in this publication of the Bureau, Technical Report No. 37 (1980).

The Australian gauge was found to record less than the pit gauge (by 2 per cent over-all) except in the case of small rain amounts (less than 3 mm) when it records more. It was also found that the effect of wind on the Australian gauge is to reduce the reading by 1.5 per cent per ms^{-1} of wind speed. The paper describes the corrections that can be applied to gauge readings to remove the small errors caused by the formation of droplets in the funnel and vessels in the gauge, and by evaporation from the gauge. Observational errors of the rainfall measurements made by trained staff are shown to be less than the resolution of the gauge.

Copies of the report can be obtained from the Director of Meteorology, Box 1289K, GPO Melbourne, 3001, Australia.

INDONESIA: Rural Water Supply, East Java Province

Background and objectives. About 90 per cent of East Java's 25.5 million population (1971 census) is rural. Of this, less than 3 per cent have access to safe water. The majority of the rural people get their water from streams, irrigation canals and ponds that are polluted. As a result, the incidence of skin and eye infections, and gastro-intestinal diseases, including cholera, is high.

The UNDP-assisted Rural Water Supply project for East Java is a follow-up of the nation-wide rural water supply project initiated by the Government in 1969. The Rural Water Supply project for East Java started in March 1975 and was completed by May 1980.

Results

This project was considered by the Indonesian Ministry of Health as the most efficient and successful of all externally-assisted water supply projects in Indonesia. Most of the project activities were carried out effectively and outputs were produced as planned. Some of the major achievements include:

1. preparation of rural water supply planning in 11 regencies in East Java;
2. preparation of preliminary engineering and feasibility studies for 7 piped water supply systems;
3. preparation of final engineering designs of 3 piped water supply systems benefiting over 60,000 people in 34 villages;
4. exploratory drilling of ground water resources in 11 regencies. Tubewells have since been drilled in the selected regencies;
5. sub-contractors' studies and recommendations on organization, management, legislation and socio-economic factors pertaining to water supply; and
6. preparation of manuals for planning, designs, operation and maintenance of water supply systems.

Financing:

UNDP: $1,185,481 Government: Rp. 232,084 million (in kind)

Water Calendar

1981

5-10 December	Dacca, Bangladesh	National Symposium on River Basin Development is being organized by the Ministry of Power, Water Resources and Flood Control, in co-operation with UNDP. Topics for discussion include development of the basins of the Ganges, Brahmaputra and Meghna rivers and similar basins elsewhere, and international river law and conventions applicable to co-operative basin development.
7-18 December	Bangkok, Thailand	Training Course on Ground Water, being organized by the UNESCO Regional Office for Science and Technology for Southeast Asia, at Jakarta, Indonesia.
11-13 December	Roorkee, India	International Symposium on Water Resources, Conservation, Pollution and Abatement. The themes of the Conference are water pollution and control; optimal utilization of water resources; transport of solids in channels; scour and sediment deposition and their effects. Contact: Dr. R.P. Mathur; Symposium on Water Resources, Conservation, Pollution and Abatement; Civil Engineering Department, Roorkee University, Roorkee U.P. 247 672, India.

1982

9-14 January	Lagos, Nigeria	Fourth ICID Afro-Asian Regional Conference on River Basin Development for Food Production includes the following topics for discussion: efficient water management in irrigation projects; problem of weeds, salinity, erosion and drainage in irrigation projects; and control of seepage in irrigation channels, particularly in field channels. For further details contact E.U. Nwa, Organizing Secretary, ICID 1982, c/o Federal Ministry of Water Resources, 9 Kofo Abayomi Rd., Victoria Island, P.M.B. 12613, Lagos, Nigeria.
18-24 January	Serdang, Malaysia	Utilization in the Humid Tropics of South-east Asia, being organized by the UNESCO Regional Office for Science and Technology for South-east Asia
19-22 January	Serdang, Malaysia	Regional Seminar on Water Technology towards Rural Development, being jointly held by the UNESCO Regional Office for Science and Technology for South-east Asia, the Universiti Pertanian Malaysia, and the Federation of Engineering Institutions in South-east Asia and the Pacific.
4-5 February	Madras, India	Eighth WEDC conference: Waste and Waste Engineering in Asia. Contact: Prof. R. Pitchai, Centre for Environmental Studies, College of Engineering, Guindy, Madras 600 025, India.
15-17 February	London, England	"Plastics and rubber in water and effluents". A conference on this subject will be held at the Royal Lancaster Hotel, London, sponsored jointly by the Institute of Water Pollution Control, the Institution of Public Health Engineers, the Institution of Water Engineers and Scientists, the Plastics and Rubber Institute and the Water Research Centre. The aim is to bring together all those concerned with the production and use of plastics and rubber in water and effluents. For further information please contact the Plastics and Rubber Institute, 11 Hobart Place, London SW1W OHL, England.

16-19 February	Singapore	Asia Aquatech '82. Contact: Lorna Miller, Asia Aquatech '82, Waalhaven ZZ 44, 3088 HJ Rotterdam, The Netherlands.
18-24 March	New Delhi, India	Thirty-third ICID-IEC Meeting.
29 March - 2 April	Cape Town, South Africa	Eleventh Conference of the International Association on Water Pollution will focus on latest research results on water pollution and its control, and on technology transfer. Contact: Secretary/Treasurer, LAWPR, Chichester House, 278 High Holborn, London WC1, England.
6-10 April	Acapulco, Mexico	International Water Decade Conference and Exhibition. Contact: Frenwest Exhibitions Limited, County House, 10, Little Portland Street, London W1N 5 DF, England.
19-30 April	Exeter, England	First Scientific Assembly of International Association for Hydrological Sciences to be convened outside the General Assemblies of the International Union of Geodesy and Geophysics will be held at the University of Exeter, supported by UNESCO and WMO. The six Commissions will each organize one symposium, and the topics are: advances in hydrometry; optimal allocation of water resources; improvement of methods of long-term prediction of variations in ground-water resources and regimes due to human activities; recent development in the explanation and prediction of erosion; hydrological aspects of alpine and high mountain areas; water quality symposium. Further information can be obtained from the Secretary, John C. Rodda, Water Data Unit, Reading Bridge House, Reading, Berkshire RG1 8PS, England.
10-12 May	Marseille, France	Fourth International Conference on Planning and Management of Water Resources for Industrial, Agricultural and Urban Use is being organized by the Commission Européenne Méditerranéenne de Planification des Eaux, in collaboration with other organizations. For further information write to Secretariat de la Conference, Société des Eaux de Marseille, 25 rue Edouard Delanglade, 13006 Marseille, France.
11-13 May	Melbourne, Australia	1982 Conference on Hydrology and Water Resources is being sponsored by the National Committee on Hydrology and Water Resources of The Institution of Engineers, Australia and the Australian Forestry Council. The Conference combines the First National Symposium on Forest Hydrology with the Institution's annual Hydrology and Water Resources Symposium, and encourages interaction between workers in the engineering and forestry streams of hydrology and water resources in Australia.
26-27 May	Rio de Janeiro, Brazil	Fourteenth Congress of ICOLD.
13-17 June	Denver, Colorado, United States	American Water Resources Association Symposium on Hydrometeorology. Contact: AWRA, St. Anthony Falls Hydraulic Laboratory, Mississippi River at 3rd Avenue S.E., Minneapolis, Minnesota 55414, Unites States.
15-18 June	Honolulu, Hawaii, United States	International Conference on Rainwater Cistern Systems. Contact: Water Resources Research Center, University of Hawaii, 2540 Dole Street, Holmes Hall 283, Honolulu, Hawaii 96822.
21-25 June	Hannover, Federal Republic of Germany	Fourth International Conference on Finite Elements in Water Resources.
31 August - 3 September	Canberra, Australia	Conference on Groundwater in Fractured Rock is being organized by The Australian Water Resources Council (AWRC) to bring together people concerned with the research, assessment and management of groundwater in fractured rock. Contact: The Secretary, AWRC Conference on Groundwater in Fractured Rock, c/o Bureau of Mineral Resources, Geology and Geophysics, P.O. Box 378, Canberra City, ACT 2601, Australia.

5-11 September	Warsaw, Poland	Third International Congress on Ecology. Contact: Prof. Dr. R. Klekowski, Institute of Ecology PAN, Dziekonow Cesny, 05-150 Lomianki, Poland.
13-17 September	Philadelphia, Pennsylvania, United States	Third World Congress on Filtration. Contact: The Filtration Society, 2 Woodstock Road, Croydon CR9 1LB, UK.
14-16 September	Nantes, France	Seventeenth meeting on hydraulics: on purification of rain water and waste water ("L' assainissement de demain: hydraulique des eaux pluviales et usées"). Contact: la Société Hydrotechnique de France, 199 rue de Grenelle, 75007 Paris, France.
21-23 September	Berne, Switzerland	International Symposium on Hydraulic Research Basins, and Their Use in Water Management. Contact: Dr. M. Spreafico, International Symposium on Hydrological Research Basins, Service hydrologique nationale, case postale 2742, 3001 Berne, Switzerland.
10-14 October	San Francisco, California, United States	Eighteenth American Water Resources Conference and Symposium. Contact: AWRA, St. Anthony Falls Hydraulic Laboratory, Mississippi River at 3rd Avenue S.E., Minneapolis, Minnesota 55414, United States.
14-19 November	Cape Town, South Africa	Eighteenth International Conference on Coastal Engineering. Topics for discussion include wind, current and wave action, tides and long waves, sedimentary processes and coastal morphology, estuary and inlet behaviour, coastal structures and recreational facilities, ship motions as related to harbour entrance design, ocean outfall design and construction, environmental aspects in coastal engineering design. Contact: Symposium Secretariat, S. 204 CSIR, P.O. Box 395, Pretoria, 0001 Republic of South Africa.

Selected Abstracts

Abstracts of current literature on water resources topics are reprinted in the following pages. Selection of the abstracts presented in each issue of *Water Resources Journal* is governed by their relevance to conditions prevailing in Asia and the Pacific, and to the objectives of water resources development programmes in the region.

The selected abstracts in this issue of the *Journal* are organized under the following topics.

Acquisition of resources data
Conservation in agriculture
Conservation in domestic and municipal use
Control of water on the surface
Data network design
Energy uses of water
Erosion and sedimentation
Evaluation process
Ground water
Social aspects of water use
Streamflow and runoff
Water in soils
Water quality control
Water yield improvement
Hydraulics

ACQUISITION OF RESOURCES DATA

"Pumping test analysis with a hand-held calculator", Frank A. Rayner.

Ground Water, ISSN 0017-467X, vol. 18, No. 6, November-December 1980, pp. 562-568.

The time-consuming curve construction and, in some cases, curve matching, and the gross approximations of aquifer geohydrologic properties, can be supplanted by a simple, speedy, accurate, and inexpensive analysis of pumping test data by a handheld programmable calculator.

With such calculators–in actuality, minicomputers–pumping test data can be analysed within seconds, while the test is ongoing, and pumping test time and expense can be reduced, while still securing representative values for transmissivity and storage coefficients.

CONSERVATION IN AGRICULTURE

"Conveyance losses in lined irrigation canal systems–a brief review", S.D.L. Luthra.

Irrigation and Power, Central Board of Irrigation and Power, Government of India; vol. 37, No. 3, July 1980, pp. 329-336.

The paper presents a review on conveyance losses in lined irrigation canal systems--Part I-Absorption or Seepage losses and Part II-Evaporation losses. It is pointed out that seepage losses which are very high in case of unlined irrigation canals varying generally between 25 to 60 per cent get very much reduced to 1/4th or 1/5th due to lining. The evaporation losses from canals, on an average, are less than 1/4th of 1 per cent of the flow as stated by Samual Fortier. Some information about observed seepage losses both in field and laboratory for lined canals is also given.

The author points out that little attention has been paid to the practical aspect of the study of evaporation losses from flowing water surfaces of irrigation canals and streams both in India and in other countries and lays emphasis on its importance.

"Primary and secondary impacts of a water resource development project", Roger B. Long.

Paper number 80080, *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 6, December 1980, pp. 1002-1005.

At a time in history when water resource development in the United States is being condemned as both economically inefficient and an environmental disaster, perhaps economists need to look back at previous development to see what the fruits of water development (be they sweet or sour) have been. The Boise Project of south-western Idaho is 70 years old and to some people it represents a gross error in resource use, while to others it represents a means of livelihood and well being. A recent research project at the University of Idaho attempted to measure not only the direct economic income benefits of the project (from irrigation), but also the indirect or secondary income benefits (from the food processing industry). Periodic regional input-output tables were constructed to assess the income generated from irrigation and food processing over the period from 1946 to 1970. Input-output analysis allowed researchers to evaluate the direct and indirect impacts of both the irrigation sector and the food processing sector and to compare their growth over time.

(KEY TERMS: irrigated agriculture; water resource development; value added income benefits; secondary benefits; input-output analysis; food processing; direct impacts; indirect impacts.)

"Projected effects of energy policies on agricultural water use and irrigation", Earl O. Heady, Burton C. English and Dan Dvoskin.

Paper number 80023, *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 6, December 1980, pp. 1012-1019.

A national and interregional programming model was used in projecting the impacts of alternative energy policies and prices on agricultural production, land use, and irrigation. The alternatives analyzed include (a) natural gas deregulation, (b) natural gas curtailment, (c) doubled energy prices, and (d) tripled energy prices. These alternatives are compared with a base alternative where prices and conditions are at normal levels. Restraints in the model control availability of water, land, nitrogen fertilizers, and energy. Water production functions were used to adjust water use to conform with projected energy prices and policies. Natural gas curtailment would have the largest effect on nitrogen use on irrigated land. Values or shadow prices for lands that remains in irrigation would increase under all of the alternatives because of reduced supply. Increased energy prices generally would increase use of surface water for irrigation and reduce use of ground water due to higher pumping costs. Reduction of 50 per cent or more in ground water use would occur in the South Central and Western regions of the United States. Water supply prices increase under all of the alternatives; with the amount varying by regions and the policy or price situation.

(KEY TERMS: linear programming; agriculture; irrigation; energy.)

"Residual power and economic feasibility of a solar-powered irrigation system", Donald E. Agthe and Dennis L. Larson.

Paper number 800094, *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 6, December 1980, pp. 1080-1083.

The problem of nonmatching irrigation and solar power production seasons creates the problem of what to do with the surplus power. The economic law of opportunity cost dictates that substitution for currently commercially purchased power is the best use for this power. This law also allows for new power using enterprises that satisfy specific criteria to be used on the farm before sale of the residual to a local public utility can be considered. Economic and financial evaluation of the solar powered irrigation system show that the price of commercially purchased power must reach 9.5 U.S. cents per Kwh before the system is feasible under the ideal assumption of complete use of the residual power to substitute for commercially purchased power.

(KEY TERMS: irrigation systems; solar power; residual power; economics.)

CONSERVATION IN DOMESTIC AND MUNICIPAL USE

"The Chicago region's valuable water resources", Clint J. Keifer.

Paper number 15569, *Journal of the Water Resources Planning and Management Division*, proceedings of the American Society of Civil Engineers, ISSN 0145-0743, vol. 106, No. WR2, July 1980, pp. 541-559.

Solution of the complex water supply problems of the Chicago metropolitan area are discussed in detail. Limitations in the use of Lake Michigan water imposed by the U.S. Supreme Court's decrees of 1930 and 1967; the overpumping and depletion of the deep sandstone aquifers; the increasing demands caused by the extensive growth of the metropolitan area; and the other uses such as lockages, leakages, navigation makeup, stormwater runoff and dilution water needed for waterway quality all add to the complexity of the water supply of this metropolitan region. Computer analyses reveal that projected future water supply demands will conflict with other uses of the 3,200-cfs allowable Lake Michigan water source. However, extensive studies show that the potential water supply deficit can be mitigated: (a) with implementation of conservation measures required by the Illinois Division of Water Resources in its water allocation order; (b) with completion and startup of the extensive pollution control facilities of the Metropolitan Sanitary District of Greater Chicago; and (c) upon success of the petition to the U.S. Supreme Court to change the Lake Michigan diversion accounting procedures.

(KEY WORDS: Aquifers; Forecasting; Great Lakes; Ground water; Public works; Regulations; Rivers; Runoff; Water consumption; Water distribution; Water resources; Water rights; Water supply)

CONTROL OF WATER ON THE SURFACE

"A study of major floods in Yamuna River in comparison to the flood of September 1978", by S.N. Chattopadhyay.

Irrigation and Power; Central Board of Irrigation and Power, Government of India, vol. 37, No. 4, October 1980, pp. 459-466.

The unprecedented flood of 1978 in the river Yamuna in Delhi has highlighted the importance of a closer study of the meteorological situations, topography of the area and changes going on there due to activity of man which are responsible for the floods of such large magnitude. In this paper an attempt is made to study the meteorological factors and the depression tracks of the previous floods in Yamuna and compare them with 1978 flood. Some of the salient features which make the flood levels go high have been identified and an overview presented. Some remedial measures to arrest the rising flood levels of Yamuna in Delhi are suggested.

"Meandering in alluvial streams and its effects on protection works", Jagdish Mohan and A.K. Agrawal.

Irrigation and Power; Central Board of Irrigation and Power, Government of India, vol. 37, No. 3, July 1980, pp. 295-298.

If a constant inflow of water and sediment travel over non-cohesive alluvium of a given grade, it develops its own meander pattern and after passage of time, meander length, meander width, and slope become steady and do not undergo further change except that there is shifting of the pattern downstream. Due to meandering characteristics the channel changes its course in wide Khadirs. This shift in river course is unpredictable and results in damage to abutments of bridges and flood embankments which cost heavy expenditure on protective works. The paper presents the studies regarding the factors responsible for the development of meanders, correlation of meander length and meander belt with hydraulic parameters on the basis of laboratory and prototype data. The effect of meander length and meander belt on protection works has also been reported in the case of Sai Aqueduct.

DATA NETWORK DESIGN

"Hydrologic networks: information transmission", William F. Caselton and Tahir Husain.

Paper number 15572, *Journal of the Water Resources Planning and Management Division*, proceedings of the American Society of Civil Engineers, ISSN 0145-0743, vol. 106, No. WR2, July 1980, pp. 503-520.

A hydrologic data collection network is considered to be a component of a communication channel conveying regional hydrologic information. A measure of the information transmission by the hydrologic network, in conjunction with spatial estimators, is derived using shannon's information theory. The resulting measure confirms that the network information transmission is dependent upon the joint entropy of the network station output but independent of the spatial estimators. Maximum information transmission is proposed as a criterion for the selection of station locations for a permanent network. A numerical example, involving the selection of station locations for various sizes of optimal information transmission hydrologic networks, is given.

(KEY WORDS: Design; Entropy; Estimation; Hydrology; Information theory; Measuring instruments; Networks; Optimization; Rainfall; Spatial distribution)

ENERGY USES OF WATER

"Installation experiences of hydro machines", by G.P. Singh.

Irrigation and Power; Central Board of Irrigation and Power, Government of India; vol. 37, No. 4, October 1980, pp. 401-406.

Water power is to play an important part in the power development programme of this country, during the course of next three decades. While every care is taken during the design and manufacture to produce good quality machines and minimize the flaws, it is impossible to eliminate the possibility of shortcomings from creeping in. It is here that the necessity of a good erection engineer is felt. Such a person is helpful not only in speeding erection and commissioning of hydro-machines, but also in identifying the repurecussions of a particular unremoved fault. Some of these flaws, may appear minor in the beginning but can be detrimental to the life and capacity of the plant. It has been tried in the following article to highlight. Some of the problems in design, and manufacturing flaws that are generally experienced during erection of hydro-machines, and corrective steps that should be taken to ensure the smooth running and longevity of plant.

"Small hydel development in India", by T.A. Deodas.

Irrigation and Power; Central Board of Irrigation and Power, Government of India; vol. 37, No. 4, October 1980, pp. 391-400.

Development of small hydro potential is gaining importance day by day especially in the wake of fuel crisis. In India the scope for development is considerable. Though the development is rather simple compared to the big hydro, there are quite a few constraints at present. Equipment, economics, lack of motivation are some of the major problems. While describing the development in India so far, nature of development, varieties of equipment utilised, relative economics and the types of problems; an attempt has been made to indicate how the development would be attractive and suggest certain measures so that an impetus is given for its development.

EROSION AND SEDIMENTATION

"Aggradation in streams due to overloading", Jagdish P. Soni, Ramachandra J. Garde and Kittur G. Ranga Raju.

Paper number 15147, *Journal of the Hydraulics Division*, proceedings of the American Society of Civil Engineers, ISSN 0044-796X, vol. 106, No. HY1, January 1980, pp. 117-132.

The problem of aggradation due to increase in the rate of sediment supply in excess of what the stream can carry has been investigated. The supply of sediment is assumed to be continuous and at a constant rate. A relationship for the depth of aggradation at any time and at any distance from the section of sediment addition has been developed. Since the mathematical model used was based on many simplifying assumptions it needed verification against a known set of data. Experiments were, therefore, performed in the laboratory and these have enabled suitable modification of the analytical results.

(KEY WORDS: Aggradation; Alluvial channels; Hydraulics; Mathematical models; Overloads; River beds; Rivers; Sediment; Sediment transport)

"Delivery of suspended sediment and pollutants from nonpoint sources during overland flow", Vladimir Novotny.

Paper number 80045, *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 6, December 1980, pp. 1057-1065.

Delivery of sediment and particulate pollutants from diffuse sources is shown to be related to the loss of sediment carrying energy of runoff during the overland flow phase. The loss is caused by the termination of rainfall and by reduction of flow energy during the recession phase of the overland flow hydrograph. It has been demonstrated both by theoretical analyses and experimental measurements that the saturated sediment concentration in overland flow is a function of rainfall erosivity and the runoff flow rate. The hypotheses were verified by field measurements from a small homogeneous watershed.

(KEY TERMS: erosion; sediment delivery; nonpoint pollution; sediment movement; overland flow; sediment yield; flow hydrograph.)

"Rates of recent sedimentation in Lake Pepin", J. Roger McHenry, Jerry C. Ritchie and Charles M. Cooper.

Paper number 80066, *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 6, December 1980, pp. 1049-1056.

Sedimentation rates since 1954 in Lake Pepin, as determined from the content of fallout cesium-137 in the sediment profile, have exceeded 2.5 cm/yr in the upper part of the lake. These rates, although somewhat less than those of the previous half century (1895-1954), are sufficiently large that the upstream portion of Lake Pepin is threatened with conversion to a marsh within a century. The density of the sediments measured increased with depth in the sampled profile from 1.1 to 1.2 g/ml at the sediment surface to 1.4 to 1.5 g/ml at 2- or 3-m depth. There was little or no change in the patterns of textural composition or density of the sediment profile with depth and age over the past 80 to 150 years.

(KEY TERMS: Lake Pepin; upper Mississippi River; sediments; sedimentation rates; sediment density; cesium-137; particle size distribution.)

"Sedimentation studies in Vaighai Reservoir using grid system", R. Jayapragasam and K. Muthuswamy.

Irrigation and Power; Central Board of Irrigation and Power, Government of India; vol. 37, No. 3, July 1980, pp. 337-350.

Grid system is one of the methods for computing the volume of deposited sediment in a reservoir. In this paper, the method of grid system adopted to compute the quantum of silt deposited in Vaigai Reservoir in between the years 1958 (year of construction) and 1976 is dealt with in detail. Different types of methods available for computing the silt volume and the advantages of grid method are summarised. How the grid method procedure followed in Vaigai Reservoir sedimentation studies is actually helpful in fixing the location of range pillar points in the base map and to check up the accuracy of the triangulation survey are explained in elaborate manner. Procedure followed in preparation of grid maps for the years 1958 and 1976, and in preparation of silt and scour map are also explained. The method of calculation to compute the sediment volume by grid method is also described. The results of computations by different methods are compared. Based on the sedimentation studies, it is concluded that the capacity of reservoir as on 1976 is 178.191 Mm^3 as against the original capacity (1958) of 194.785 Mm^3. Average annual silting rate is 0.477 per cent. Average annual rate of sedimentation per km^2 of catchment area is 409 Mm^3/km^2. Generally deposition occurs all along the deep course and scour is observed near FRL range. The useful life of reservoir has been estimated to be 155 years.

EVALUATION PROCESS

"A retrospective benefit-cost analysis of water resource projects in the Cumberland River basin", W. Josep Martin and Edward L. Thackston.

Paper number 80043, *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 6, December 1980, pp. 1006-1011.

A retrospective benefit-cost analysis of major water resources projects in the Cumberland River basin was conducted. The U.S. Army Corps of Engineer's projects selected were Dale Hollow, Wolf Creek, Center Hill, and J. Percy Priest Reservoirs. The ex-post performance of the evaluated reservoirs were compared to the ex-ante estimates.

Benefits and costs for each project were deflated to their base year and respective average annual values for each of these components were calculated. An ex-post benefit-cost ratio was determined for each project, as well as the combined system. The benefit-cost ratio for each project surpassed unity. The actual ratio as compared to the ex-ante estimate for each project is as follows: Dale Hollow, 1.24 to 1.46; Wolf Creek, 1.40 to 1.53; Center Hill, 1.17 to 2.02; and J. Percy Priest, 1.45 to 1.6. The internal rate of return was also determined for each project.

The results obtained for each project are tabulated and discussed with consideration given to factors effecting the economic evaluation of the projects.

(KEY TERMS: benefit-cost analysis; ex-post performance; ex-ante estimates; internal rate of return.)

GROUND WATER

"A rational approach to ground-water exploitation by shallow tubewells in the Karnal region", N.K. Tyagi, O.P. Singh, V.V. Dhruva Narayana and R.K. Gupta.

Irrigation and Power; Central Board of Irrigation and Power, Government of India; vol. 37, No. 2, April 1980, pp. 241-247.

There is appreciable gap between the potential discharge and pumping efficiencies of the shallow tubewells at the farmers field and the research farm. The two important factors that are responsible for low well yields are higher suction heads and lower spacing. Other factors like improper maintenance of the pumps and motor, development of tubewell cavities and faulty design of the pumps themselves could also be possible reasons of low discharge and needs further investigations. The present situation can be improved by adopting the following measures:

(a) Keeping pumps at 2.5 m from ground surface from February to July and at 1.0 m from August to January.

(b) Adopting a spacing of 200 m with a tubewell density of 30 per km^2.

(c) In all cases except when specifically specified by the technical person, motors of more than 5 horsepower should not be installed on shallow tubewells in this region.

(d) The number of tubewells required to meet the irrigation demand can be reduced by adopting suitable cropping pattern as indicated in figure 4.

"Bottled waters—expensive ground water, Joseph R.J. Studlick and Richard C. Bain.

Ground Water, ISSN 0017-467X, vol. 18, No. 4, July-August 1980, pp. 340-345.

Due to the growing demand for bottled mineral waters, a study was undertaken to determine the quality of fourteen different brands of still and sparkling bottled waters. Objective testing showed a wide variance in taste as waters have different tastes and individual preferences are the rule. By analytical means, the mineral content of most of the tested waters met U.S. Environmental Protection Agency standards; however, some samples

had unacceptable levels of sulfate, hardness, and other constituents. Cost comparisons show a wide variation in price, with all the tested waters many times more than normally available tap waters.

"Computer models in ground-water exploration", Irwin Remson, Steven M. Gorelick and Julianne F. Fliegner.

Ground Water, ISSN 0017-467X, vol. 18, No. 5, September-October 1980, pp. 447-451.

Four case histories illustrate the various roles that digital computer simulation models can play in ground-water exploration. The case histories describe their use in evaluating aquifer parameters and characteristics, in estimating ground-water recharge, in resolving data inconsistencies, and in determining the optimal allocation of exploration funds. The models are especially useful in identifying data deficiencies and inconsistencies.

"Determining impact of irrigation on ground water", Irfan A. Khan.

Paper number 15927, *Journal of the Irrigation and Drainage Division*, proceedings of the American Society of Civil Engineers, ISSN 0044-7978, vol. 106, No. IR4, December 1980, pp. 331-344.

Agriculture in arid and subarid regions comprising some 22 per cent of the world's arable land, depends on supplemental irrigation. Irrigation eventually may lead to salinity problems and has led to the theory that a civilization cannot long endure when dependent on irrigated agriculture. However, effective planning and management could delay or perhaps avert the ultimate destruction of the irrigated system. It may be too late for an effective action if the symptoms of salinization have already begun. A simple inexpensive modeling procedure is described here which may be used to determine the long term effects of irrigation and agricultural practices on the system. Pauma subbasin in southern California is used to demonstrate the application of the model.

(KEY WORDS: Ground water; Groundwater management; Irrigation; Irrigation practices; Management; Model studies; Saline groundwater; Salinity.)

"Electric logging techniques applied to ground-water exploration and water wells", B.S. Tanwar.

Irrigation and Power; Central Board of Irrigation and Power, Government of India; vol. 37, No. 2, April 1980, pp. 233-240.

The exploration of ground water supplies primarily aims at: (a) location of sub-surface water bearing formations, (b) determination of quality of interstitial water; and (c) estimation of yields. Similarly, the construction of water wells involves scientific designs to achieve optimum efficiency in extraction of ground water at a minimum cost without any troubles.

Electric logging techniques in suitable bore-hole conditions are very helpful in the investigation of ground-water supplies and economic designs of water wells.

The conventional single electrode logging device is widely employed in ground-water and water-well investigations, which provides considerable qualitative information rapidly and at low expense. This paper deals with the principles of logging, equipments, procedure of recording an electric log, field practices, interpretation problems, and advantages of the logging and its limitations.

SOCIAL ASPECTS OF WATER USE

Socio-cultural Aspects of Water Supply and Excreta Disposal, by Mary Elmendorf and Patricia K. Buckles.

Washington, D.C., World Bank, 1978.

Social and cultural factors influencing people's responses to water supply and excreta disposal technologies are investigated in eight case studies of communities in the rural and urban fringe areas of Latin America. Part 1 describes the methodology and questionnaire used to investigate how sanitation and water supply problems are perceived and to what extent people would be willing to participate in projects to improve their existing situation. Part 2 summarizes each case study, including the technologies introduced and community response to them. Part 3 presents the cross-community findings on perceptions, preferences, related practices, and the use of social science techniques to understand them. In Part 4, the report focuses on the implications of the findings and suggests an approach which can be used by planners to integrate social and cultural factors into project design to ensure the introduction of water supply and excreta disposal technologies which will be accepted, properly used, and maintained.

This report was prepared as part of the World Bank research project an Appropriate Technology for Water Supply and Waste Disposal. Complete reports on the eight case studies can be obtained from the EWT Department upon request.

STREAMFLOW AND RUNOFF

"River formulae", Shrikrishna V. Chitale.

Irrigation and Power; Central Board of Irrigation and Power, Government of India, vol. 37, No. 2, April 1980, pp. 205-218.

River formulae for estimation of width, depth, slope, velocity and bed material size have been

advocated by several authors. Practice of adoption of canal formulae for this purpose is also in vogue. Information on quantitative assessment of the relative accuracy of the various formulae is however not available in literature. Choice of dependable river formulae is important while designing and constructing river engineering works to ensure their economy and safety. The paper attempts to collate more important formulae in common use and to determine their accuracy on basis of observed data in respect of rivers primarily in India and the United States of America. Finally, some accurate formulae are cited.

"Computation of the flow in shallow river bends", J.P. Th. Kalkwijk and H.J. de Vriend.

Journal of Hydraulic Research, International Association for Hydraulic Research, ISSN 0022-1686, vol. 18, No. 4, 1980, pp. 327-342.

The mathematical model presented describes the flow in rivers of which

1. the depth is small compared with the width,
2. the width is small compared with the radius of curvature,
3. the horizontal length scale of the bottom variations is of the order of magnitude of the width.

Within these limits, the channel alignment can be arbitrary and it is not necessary that the width is constant. Furthermore, it is assumed that

4. the flow is mainly friction controlled,
5. the longitudinal component of the velocity is predominant,
6. the Froude number is small.

The final set of differential equations accounts for the longitudinal convection (Bernoulli effect), the bottom friction, the flow curvature and the transverse convection of momentum by the secondary flow. The numerical integration procedure is straightforward and requires little computation time. Computational results are presented for a large hydraulic model which fulfills the above conditions.

"Stochastic generation of annual streamflows", R. Srikanthan, and Thomas A. McMahon.

Paper number 15935, *Journal of the Hydraulics Division*, proceedings of the American Society of Civil Engineers, ISSN 0044-796X, vol. 106, No. HY12, December 1980, pp. 2011-2028.

Various short and long memory annual streamflow generation models are described and applied to a set of Australian streams. Based on the results, a Markov model is recommended for streams having small Hurst coefficient while for moderate to large Hurst coefficients, a broken line model is satisfactory.

(KEY WORDS: Coefficient; Data handling; Hydrology; Memory; Models; Stochastic processes; Stream flow)

WATER IN SOILS

"Aquifer response in the ultramafic field area of Sukhinda Valley-Orissa (India)", I. Radhakrishna and T. Venkateswarlu.

Ground Water, ISSN 0017-467X, vol. 18, No. 5, September-October 1980, pp. 479-485.

Analysis of a long-duration aquifer performance test utilizing a well near Kansa in the Sukhinda ultramafic body of the Cuttack District in Orissa has demonstrated that nonequilibrium formulae can be applied to hard-rock regions depending upon the stage of hydrogeological regime and the vertical leakage in the system. Graphical analysis of test results under nonsteady and steady-state conditions have helped in understanding the behavior of aquifers and their characteristics. A comparative examination of results obtained by different methods and careful insight has helped in delineating the boundary conditions, long-term withdrawal effects and well spacing problems in the present area, and this approach could be applied in similar well fields.

WATER QUALITY CONTROL

"The use of biological criteria in environmental policy", Peter N. Nemetz and Herbert D. Drechsler.

Paper number 80056, *Water Resources Bulletin*, American Water Resources Association, ISSN 0043-1370, vol. 16, No. 6, December 1980, pp. 1084-1093.

The hypothesis of this paper is that regulatory systems for the control of effluent released to the environment can be, if improperly designed, inadequate for both the establishment of effective pollution control policy and the assessment of the biological significance of violations. This inadequacy may stem from several factors: first, the use of single point standards which delineate the boundary between legally acceptable and unacceptable pollutant discharges; and second, the existence of significant weaknesses in the frequency and design of monitoring programmes. In order to be effective, pollution standards must reflect the impact of pollutants on the ecosystem. To achieve this goal, three critical pieces of information are required: measurement of ambient levels of released pollutants, frequency distributions derived from these data, and estimates of biological damage functions. Illustrating the above three requirements with data drawn from research in British Columbia, the authors recommend a restructuring of environmental policy to provide

regulatory agencies with an effective mechanism for the analysis and control of environmental degradation.

(KEY TERMS: water pollution control; monitoring programmes; biological damage functions; frequency distributions.)

WATER YIELD IMPROVEMENT

"Glacial melt water in Greenland: a renewable resource for the future", by George R. Alther, Lon C. Ruedisili, Hans Stauber and Curt F. Kollbrunner.

Energy Research, John Wiley & Sons, Ltd., ISSN 0363-907X, vol. 5, No. 2, April-June 1981, pp. 183-190.

Melt water available from ice caps and glaciers, such as that found in southern Greenland, can be used as a renewable resource for a large scale hydropower project. Previous researchers have assessed the technical and economical feasibility of such a project, with the idea that harnessing this almost unlimited resource could help to solve our energy shortages. This article presents a brief state-of-the-art review concerning resource availability, the utilization and methodology for a glacial power station and some alternative beneficial uses for glacial melt water.

Hydropower is to be harnessed by using existing melt water channels and lakes on the ice cap of southern Greenland and/or by melting a prepatterned system of channels and reservoirs into the ice cap. Natural protruding rocks ('nunataks') could be used as natural dams for the reservoirs, eliminating the costly construction of artificial dams. The collected melt water is to be channelled through penstocks to fiords at sea level–a 2000 m drop–where it will feed the turbines of power plants. Water discharged from the turbines could then be pumped directly into tankers or huge plastic hoses. The latter would be towed by tugs to drought stricken areas to provide drinking and irrigation water. Furthermore, liquid hydrogen and oxygen could be generated locally from the discharge water by electrolysis and shipped all over the world. Long distance transport of bulk energy is proposed in the form of sea cables and overland transmission lines, hydrogen gas pipelines and tankers for liquid hydrogen transport (or ammonia).

The advantages of this project are: (1) an energy source which causes virtually no pollution; (2) cheap exploitation costs due to drilling, mining and other exploration and production costs being eliminated, (3) construction and transport facilities costs compatible with present U.S. energy source development; (4) pre-planning and engineering problems can be minimized because of practical experience gained by some alpine countries; and (5) completion within twenty years, and much sooner if alternative uses of glacial melt water are utilized.

(KEY WORDS: Southern Greenland; Glacier; Glacial meltwater; Resource hydroelectric power plants; Hydrogen; Nunataks; Runoff; Fresh water; Reservoirs; Channels; Sea cable systems; Ammonia)

HYDRAULICS

"Programmable hand-calculator programmes for pumping and injection wells: III–Constant pumping (injection) rate, fully confined aquifer, partially penetrating well", Don L. Warner and M. Gene Yow.

Ground Water, ISSN 0017-467X, vol. 18, No. 5, September-October 1980, pp. 438-443.

Programmable calculator programmes have been given previously for the calculation of head or pressure change resulting from the pumping from or injection into wells completely penetrating fully confined or semiconfined aquifers. Programmes are documented here for wells partially penetrating a fully confined aquifer. The programmes are for the TI 59 card programmable calculator.

"Head-loss measurements on hydroelectric conduits", by T. Maxwell Brett.

Paper number 15109, *Journal of the Hydraulics Division*, proceedings of the American Society of Civil Engineers, ISSN 0044-796X, vol. 106, No. HY1, January 1980, pp. 173-190.

Prototype head-loss measurements on tunnels and other water conduits are reported. The measurements were done on water-power conduits of the Hydro-Electric Commission of Tasmania, Australia. Friction Friction factors are given for an unlined tunnel, a mechanically bored partly lined tunnel, and a fully lined tunnel. Steel and woodstave friction factors are included together with factors for a concrete-lined trapezoidal canal. The effect of slime growth on head losses is discussed.

"Flow in a channel with a slot in the bed", M.S. Nasser, P. Venkataraman and A.S. Ramamurthy.

Journal of Hydraulic Research, International Association for Hydraulic Research, ISSN 0022-1686, vol. 18, No. 4, 1980, pp. 359-367.

This paper presents a theoretical and experimental analysis of flow in a channel with a bed slot spanning the entire width of the channel.

A simple theoretical expression derived for the coefficient of discharge for the bed slot is substantiated by experiments. Resolution of the momentum equation along the flow direction yields a simple equation for the brink depths ratio which is verified by experiments.

The influence of the slot length on the diverted discharge is evaluated and an empirical formula describing the relationship is proposed.

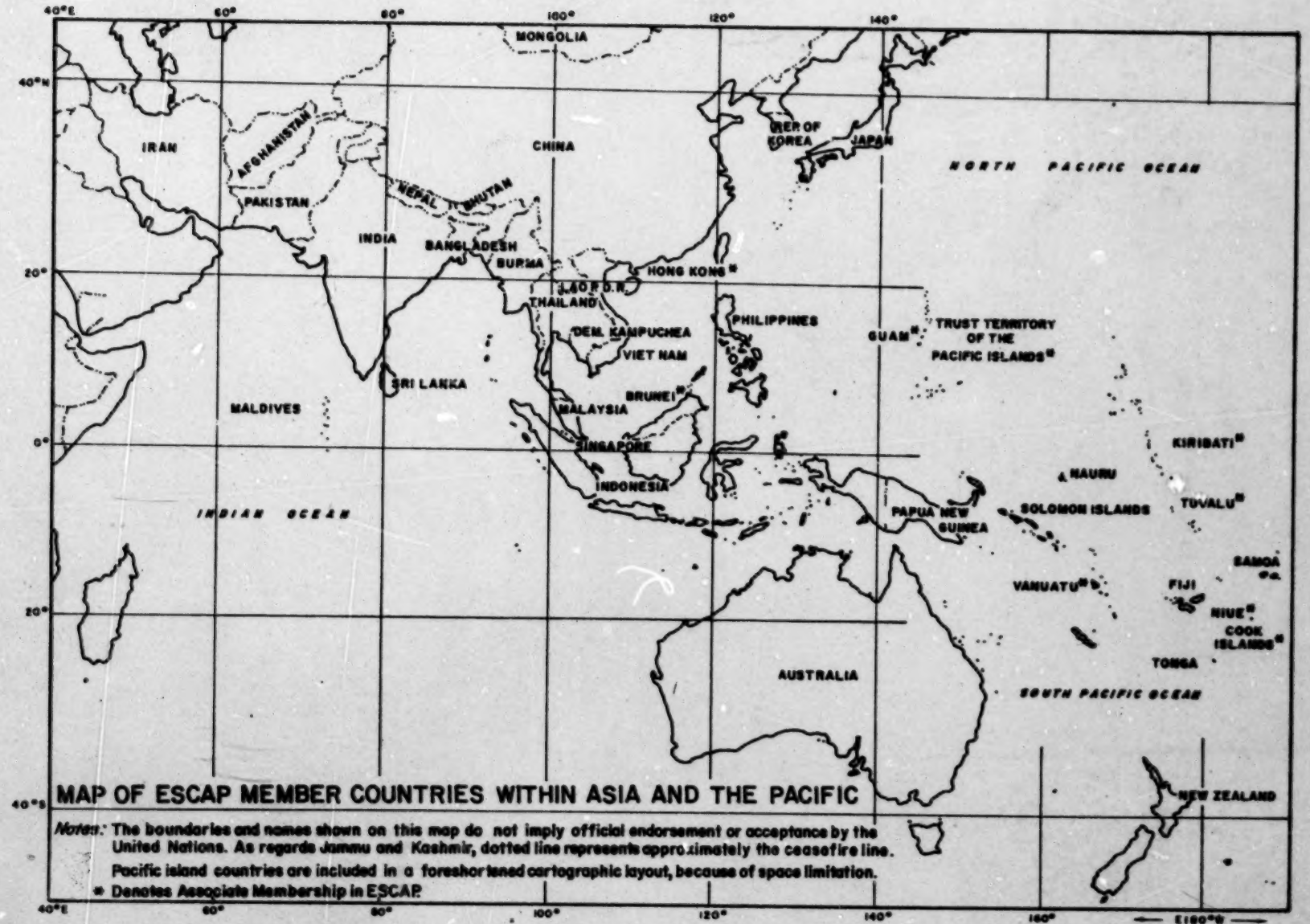
ABBREVIATIONS USED IN THIS ISSUE

Measurements

A	ampere	l	litre
cm	centimetre	m	metre
ft	foot	m^3	cubic metre
GWh	gigawatt hour	mi^2	square mile
h	hour	min	minute
ha	hectare	ms^{-1}	metres per second
hp	horsepower	MW	megawatt
hPa	hectoPascal	Nr	Nepal rupee (currency)
in	inch	Nu	ngultrum (Bhutanese currency)
kg	kilogram	PVC	polyvinyl chloride
km	kilometre	rev/min	revolutions s per minute
km^2	square kilometre	sec	second
kV	kilovolt	Tk	taka (Bangladeshi currency)
kVA	kilovolt-ampere	V	volt
kW	kilowatt	W	watt
kWh	kilowatt hour	yr	year

Organizations

ADB	Asian Development Bank
AIT	Asian Institute of Technology
ASCE	American Society of Civil Engineers
AWRA	American Water Resources Association
IAHR	International Association for Hydraulic Research
IAHS	International Association of Hydrological Sciences
IFAD	International Fund for Agricultural Development
UNCDF	United Nations Capital Development Fund
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations Children's Fund
UNIDO	United Nations Industrial Development Organization
UNU	United Nations University
USAID	United States Agency for International Development
WFP	World Food Programme
WHO	World Health Organization
WIC	Water Information Center, Inc.
WMO	World Meteorological Organization



MAP OF ESCAP MEMBER COUNTRIES WITHIN ASIA AND THE PACIFIC

Notes: The boundaries and names shown on this map do not imply official endorsement or acceptance by the United Nations. As regards Jammu and Kashmir, dotted line represents approximately the ceasefire line.

Pacific island countries are included in a foreshortened cartographic layout, because of space limitation.

* Denotes Associate Membership in ESCAP.